PERFORMANCE OF LUCERNE/GRASS MIXTURES UNDER DIFFERENT GRAZING DURATIONS AND SOIL DEPTHS IN A DRYLAND ENVIRONMENT

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Two studies were conducted on pure WL320 lucerne, lucerne/ 'Grasslands Matua' prairie grass and lucerne/'Grasslands Maru' phalaris mixtures at Lincoln University, between April 1988 and September 1989. The 0.042 ha plots were sown in early November 1986 into a Templeton fine sandy loam soil. The weather during the experimental period was very dry during spring and summer, but was warm and moist in winter.

The first study investigated the effects of short (3-7 days) and long (6-14 days) sheep grazing durations on the three pastures. Short grazing resulted in 15% more total yield from six grazing cycles (15000 versus 13000 kg $DMha^{-1}$). There were no significant differences in total yields between the pastures. Total lucerne yields were 20% higher under short duration for pure lucerne and lucerne/phalaris, but were not different for lucerne/prairie grass. The total yield of prairie grass under short grazing (9160 kg $DMha^{-1}$) was 36% higher than under long grazing (6740 kg $DMha^{-1}$), but phalaris yields were similar at 2570 and 2320 kg DMha-1 respectively for short and long grazing. The results indicated that short grazing duration was superior to long grazing duration, when rotation lengths were equal.

The second experiment compared the performance of lucerne with the lucerne/grass mixtures in shallow (<50 cm) and deep (>80 cm) soils on mini-plots of 8 m^2 selected from areas within the grazed plots. Water use from the soil was measured using a neutron probe. Root cores were sampled in May 1989 from deep soil plots.

On the shallow soils total yields from pure lucerne and lucerne/phalaris were similar (11700 and 11400 kg $DMha^{-1}$) and were significantly higher than the lucerne/prairie yield of

8500 kg $DMha^{-1}$. Pure lucerne and lucerne/prairie yields were 17% and 45% higher in the deep soils than in the shallow soils, but in both soil types, lucerne/phalaris yields were similar. Winter yields from pure lucerne and lucerne/prairie were similar on both soils (3000 kg $DMha^{-1}$), but lucerne/phalaris produced 27% more on shallow (3700 kgDMha-1) than on deep soils (2900 kg $DMha^{-1}$). Total lucerne production in lucerne/phalaris of 9900 kg $DMha^{-1}$ was not affected by soil depth but in lucerne/prairie, lucerne yield was 57% less on shallow (3950 kg $DMha^{-1}$) than on deep soils (9100 kgDMha-1). Total yields from prairie grass and phalaris were higher by 30% and 10% respectively on shallow soils.

Total water use was not different between the pastures at 384, 376 and 375 mm respectively for lucerne, lucerne/prairie and lucerne/phalaris, but was 10% higher on deep soils (398 mm) than on shallow soils (360 mm). Seasonal water use was similar for all three pastures and was higher in deep soils by 39% in spring and 20% in early summer. All three pastures showed similar water use efficiency (WUE) in deep soils but in shallow soils, the WUE of lucerne/prairie was significantly lower (10-13 $kgDMmm^{-1}H_2O$) than either the lucerne or the lucerne/phalaris mixture (18-24 $kgDMmm^{-1}H_2O$). Pure lucerne extracted water from greater depth than the mixtures. Under all pastures, water was extracted until soil volumetric water content reached 10%. Pure prairie grass and phalaris had 70% and 50% of their roots in the top 20 cm, and roots of both grasses were traced to 70 cm depth. In the top 20 cm lucerne root yield of lucerne/prairie was only 60% (4 $kgDMm^{-3}$) compared to 88% (9 $kgDMm^{-3}$) of lucerne/phalaris at that depth.

The results showed that under the extremely dry conditions of 1988/89, there was no advantage in pasture yield of lucerne/grass mixtures over pure lucerne. However the inclusion of phalaris in shallow soils and prairie grass in deep soils provided effective weed control and good cool season growth without adversely affecting pasture productivity.

KEYWORDS : WL 320 Lucerne; *Medicago sativa* L.; "Grasslands Matua" prairie grass; *Bromus willdenowii* Kunth; "Grasslands Maru" phalaris; *Phalaris aquatica* L.; Lucerne/grass mixtures; Grazing duration; Dry matter yield; Seasonal production; Soil depth; Water use; Water use efficiency; Water extraction pattern; Root yield.

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CHAPTER 1

INTRODUCTION

1.1. GENERAL INTRODUCTION

The consequences of the greenhouse effect, although controversial, are a matter of rising concern and speculation among scientists all over the world. A global rise in temperature is predicted which would alter the environment of agro-ecosystems. For the Canterbury Region of New Zealand, a warmer, drier climate is predicted with 1.5^{o}C warmer temperatures, 5% less rain and 150 hours more sunshine (New Zealand Ministry of Energy, 1989). Under these predicted environmental conditions, the potential of lucerne/grass mixtures may be more widely recognised as an alternative to the conventional ryegrass/white clover or pure lucerne (*Medicago sativa* L.) pastures especially under dryland conditions. Irrigation would normally be required if the conventional ryegrass/white clover pasture is used due to its poor production and persistence under drought conditions (Langer, 1982; Smetham, 1982). While pure lucerne is resistant to drought and is superior to other options under these conditions (Douglas, 1986), its strong seasonality of growth remains a major drawback. Most lucerne cultivars remain dormant during winter and early spring growth is poor relative to grasses (Hoglund, *et al.* 1974). Early spring is a critical time in New Zealand pastoral farming due to the high lactation feed requirement after calving and lambing.

Lucerne/grass mixtures have the potential to exploit the total environment for light, moisture and nutrients due to their contrasting physiological and morphological differences and thereby, overcome the problems of conventional pastures or pure lucerne. By using a winter active grass, better spread of production could theoretically be achieved since the cool season growth of the grass component will complement the high summer productivity of lucerne. The deep roots of lucerne will be able to utilise moisture and nutrients from depth, while the shallower roots of the companion grass will be able to use moisture and nutrients nearer to the soil surface. Lucerne is a highly efficient nitrogen fixing legume and may therefore, transfer adequate amounts of nitrogen to the associated grass. The inclusion of grasses in mixtures with lucerne also overcomes the problem of weeds faced in monoculture lucerne. This is particularly due to the reduction in available space and light for weed growth.

The main requirement of grasses in a mixture with lucerne is to give good seasonal growth in winter and early spring, but not to be so competitive in spring and summer that the growth of lucerne is restricted (O'Connor, 1967). Although a combination of winter-active grass with a summer-active lucerne should be ideal, many of the mixtures tried in the past were unstable becoming either grass or lucerne dominant with time. Reasons suggested for this instability were unfavourable defoliation practices (Langer, 1973; Xu, 1989), inappropriate establishment methods (Vartha, 1967), and high interspecific competition for light, nutrients and moisture between the lucerne and the grass components of the mixture (Leach, 1979). Grass species previously tried in New Zealand include cocksfoot (*Dactylis glomerata* L.), tall fescue (*Festuca arundinacea* Schreb), perennial ryegrass (*Lolium perenne* L), annual ryegrass (*Lolium multiflorum* L.), timothy (*Phleum pratenses* L.), phalaris (*Phalaris aquatica* L.) and prairie grass (*Bromus willdenowii* Kunth) (Cullen, 1965; Iversen, 1965; O'Connor, 1967; Vartha, 1973; 1976; Fraser, 1982, 1983; Moot, 1986; and Xu, 1989). Of these species, prairie grass "Grasslands Matua" (Fraser, 1982; Xu, 1989) and phalaris "Grasslands Maru" (Moot, 1986; Xu, 1989) were recommended as promising companion grasses for lucerne. However, the above evaluations were of a short term nature involving only one to two years, and therefore, require further investigation over a longer period of time especially in dryland areas under grazing conditions.

1.2. OBJECTIVES

Very few grazing management studies on lucerne/grass mixtures have as yet considered the influence of grazing duration. O'Connor and Vartha (1968) studied just one regrowth period, and Xu (1989) studied the grazing duration influence over four grazing cycles up to 18 months following establishment. Both these studies showed that long duration grazing favoured lucerne growth in the mixture while short duration favoured grass growth. Therefore, the first part of this study was concerned with examining the longer term effects of long and short grazing durations on the performance of pure lucerne, lucerne/prairie grass and lucerne/phalaris mixtures by continuing the work initiated by Xu (1989) using the same pasture plots. This may result in the identification of grazing management systems which could be used to manipulate the seasonal balance of lucerne and grass components in the two mixtures to obtain maximum production as well as persistence.

Most studies in Canterbury and Otago on lucerne/grass mixtures where increased yields were reported, have been carried out under favourable soil moisture conditions and over a short period of one to two years (Cullen, 1967; O'Connor and Vartha, 1968; Vartha, 1973; Fraser, 1982, 1983). It is expected that under dryland conditions with high soil moisture deficits, lucerne/grass mixtures may not produce higher yields than pure lucerne because of the competition for the limited soil water available. Under such conditions, soil profile depth, may have a major influence on pasture production because of differences in soil water storage capacity and potential rooting depth of different species. It is expected that the shallower rooting prairie grass may hypothetically be less competitive than deep rooting phalaris since it will not be as competitive for soil moisture at depth with lucerne.

Therefore, the second aim of this study was to determine whether it is beneficial to grow lucerne/grass mixtures in preference to pure lucerne and if so, which of the two grass species is better suited for dryland shallow or deep soil. Comparisons will be drawn between pure lucerne, lucerne/prairie grass and lucerne/phalaris for annual and seasonal dry matter production, botanical composition, water use and water use efficiency.

CHAPTER 2

REVIEW OF THE LITERATURE

2.1 INTRODUCTION

Lucerne is traditionally grown as a monoculture in New Zealand, and therefore research efforts in the past have mainly been concerned with the agronomy and physiology of lucerne in pure stands. Relatively few studies have been conducted on lucerne/grass mixtures in general and on interspecific competition between lucerne and companion grasses in particular. Most of the literature available originates from work done in North America.

This review aims to cover the limited literature available from work done in New Zealand and where relevant from other sources, to cover the interspecific competition, establishment, management and adaptation to water stress of lucerne/grass mixtures.

2.2 INTERSPECIFIC COMPETITION IN LUCERNE/GRASS MIXTURES

A botanically stable and productive lucerne/grass mixture is often difficult to maintain because of a high degree of competition between its components. This section reviews the competition for light, water and nutrients between lucerne and grasses when grown in mixtures.

2.2.1 Competition for light

In order to reach its genetic potential, a plant needs to be able to intercept maximum light. A mixed pasture, such as lucerne/grass, may develop sufficient foliage within a few days after seedling emergence to begin competition for light (Chamblee and Collins, 1988). Light is a critical factor in the growth of lucerne as well as in the companion grass. Pritchett and Nelson (1951) found that dry weights of both lucerne and bromegrass (*Bromus inermis Leyss.*) in a mixed sward were reduced as light intensity was decreased. Lucerne nodulation was decreased as well and was completely inhibited at 55 μmol photon $m^{-2}s^{-1}$.

Grasses may offer competition at various stages of growth, particularly as new growth arises from the crown buds of lucerne. Following defoliation, grasses grow not only from the cut stems and tillers, but also from new tillers at the base, whereas lucerne grows from new shoots at the stem base. Hence grasses recover faster from defoliation and regrow more rapidly leading to the shading of lucerne crown buds, which may consequently fail to develop as shown by Chamblee and Lovvorn (1953) with lucerne/tall fescue mixtures. Thus under too frequent grazings, lucerne growth is suppressed as regrowth is slower and leads to shading from grasses. On the other hand, it was suggested that lucerne may produce a favourable light environment for the growth of companion grass species because of its spatial canopy (Chamblee and Collins, 1988).

Lucerne swards appear to have the photosynthetic potential to respond to higher light intensities than swards of many other pasture legumes (Brown et al., 1966; Wilifong et al., 1967; and Heslechurst and Wilson 1974 cited by Leach, 1979). In artificial swards, lucerne showed increases in photosynthesis even up to a leaf area index (LAI) of 10 (King and Evans, 1967). This suggests that lucerne has an advantageous canopy structure which enables adequate light penetration to lower levels and leads to more efficient light use by the whole canopy. The manner in which lucerne is utilised, with intermittent heavy grazing or cutting, produces periods of several days before sufficient new leaf is displayed to intercept most of the radiation (Stanhill, 1962). As a result, appreciable loss of potential production occurs (Leach, 1979).

Interactions between light, nutrients, moisture and defoliation practices exist. Competition for light could reduce root size and render a plant less competitive for soil nutrients and water. The rate of defoliation will change the light regimes in the canopy either slowly or rapidly to advantage either lucerne or grass.

2.2.2 Competition for moisture

It is generally acknowledged that lucerne competes favourably for available soil moisture with grasses (O'Connor, 1967; Langer, 1979; Douglas, 1986). O'Connor (1967) stated that in shallow soils lucerne, especially at the seedling stage, may suffer from moisture competition, but once established, lucerne is able to exploit soil water effectively in moderate to deep soils. Under low moisture conditions (rainfall less than 250 mm in growing season),

Lorenz et al. (1961) found that the lucerne component in a lucerne-bromegrass mixture decreased to 25% by the autumn of the third year. Under humid conditions, Ward et al. (1966) found that the cocksfoot component of a lucerne/grass mixture was increased more by irrigation than was the lucerne component. The favourable competitive performance of lucerne, when grown with grasses in certain environments, results not only from lucerne obtaining water at lower depths than grasses, but also from the equal competition of lucerne with grasses for available soil moisture in the upper soil levels (Powell and Kardos, 1968).

Considerable variation in competetiveness exists between grasses. Fraser (1982) reported that Maru phalaris made little contribution to total yield under dryland conditions but made a substantial contribution under irrigation over a three year period at Lincoln (Fraser, 1983). From the same experiments, Fraser also showed that Matua prairie grass competed favourably with lucerne under both conditions. This was probably due to the fact that phalaris, being a deep rooted grass (McWilliam and Kramer, 1968; Rumball, 1980) competes for the same space as lucerne, while Matua is better able to coexist because of its shallower root system, which enables it to use surface moisture more effectively.

In extremely dry years, grasses may dominate lucerne since soil water at depth, especially after dry winters will be very low, and lucerne may not be competitive with shallow rooting grasses for surface moisture from light rainfalls. In many dryland regions, particularly those with Mediterranean or sub-tropical climates, soil is only recharged with water to a limited depth each year and the advantage of the deep, tap-rooting habit of lucerne is less evident. Snaydon (1972) showed that production at Canberra, Australia through the summer months depended on rainfall during the growing season, because of inadequate stored soil moisture. The tap root may, however, be important for ensuring survival through long drought, much as described for summer survival of phalaris by McWillam and Kramer (1968).

2.2.3 Competition for nutrients

Drake *et al.* (1951) studied the cation-exchange capacity (CEC) of lucerne and perennial grasses and found that lucerne roots had nearly double the CEC of grasses. Thus lucerne could absorb relatively more divalent cations such as Ca, than grasses. On the other hand, grasses were better competitors for K in a soil low in available K (Drake *et al.* 1951; Langille *et al.* 1965). Grass dominance is thus often attributed to this factor especially under a cut and carry system (Blaser and Brady, 1950). There is also some evidence that lucerne

suffers from competition by companion grasses for available soil S and K and even for P during establishment (O'Connor, 1967). However, once established it competes strongly when P is limiting, since its root system extends deeper than associated grasses and is able to extract P at depth (Chamblee and Collins, 1988). The same may apply to situations when S is limiting as S is more leachable to lower soil depths (Jones, 1970).

McLeod (1965) found that the addition of K increased lucerne root yields while N fertilization caused a decrease. Studies by Chamblee (1953) in North Carolina, USA, showed that lucerne grown with tall fescue had a lower K content than when grown with cocksfoot. However, when K was available in sufficient amounts for both components, the lucerne dominated the grass (Hunt and Wagner, 1963; McLeod and Bradfield, 1963). Fertilizer practices aimed at maintaining abundant K, and marginal topsoil P and S, can foster lucerne at the expense of grasses. Its deep root system may give lucerne some advantage where nutrients such as P and S are leached below the depth from which they can be absorbed by shallow rooted companion species (Jones, 1970; Leach, 1979). More often though, inadequate nutrients may limit the exploitation of subsoil moisture (Simpson and Lipsett, 1973). In dry regions, surface-applied nutrients may remain less available to lucerne than to surface rooting species (Brownlee et al. 1975). Studies in Canada by Kilcher (1966) showed that nitrogen application of 90 $kgha^{-1}$ with or without added P, increased yields and maintained 40% grass in the mixture. Where N was omitted, or where P only was added, the grass component was about 12%.

The need for N application to encourage grass growth has been well demonstrated by O'Connor (1967) at Lincoln. However, the possible manipulation of swards by regulating the supply of P, S and K remain unexplored in New Zealand.

2.2.4 Effects of temperature

Temperature affects growth and evapotranspiration and therefore indirectly affects competition. Lucerne emerged more rapidly than bromegrass or cocksfoot at lower soil temperatures, but subsequent vegetative development of lucerne was retarded more by cold soil than was that of the grasses (Stafford, 1969 cited by Chamblee and Collins, 1988). Optimum temperatures for growth of lucerne and for cocksfoot have been reported as 21 and 17^{o}C respectively (Nielsen *et al.* 1961). More recently, a number of relatively winter-active cultivars

of lucerne (e.g. AS13R), which may have lower optimal temperatures, have become available. They may offer increased competition to grasses in winter and may even reduce total herbage production as a result. However, winter active lucernes could be less competitive in spring because of lower root reserves, which were used for winter growth (White and Lucas, 1989) and may result in lower spring and summer production.

2.2.5 Nitrogen fixation and transfer by lucerne

The possible mechanisms involved in the transfer of N from the legumes to the associate grasses include: direct excretion of organic N compounds by nodulated legume roots (Ta *et al.*, 1986), decomposition of dead nodule and root tissue (Butler and Bathurst, 1956; Butler *et al.*, 1959); and leaching by rain of minor amounts of N from legume leaves; release from decaying leaves (Ta et al. 1986); and transfer through animal excreta (Arnold, 1981).

In high yielding crops, pure lucerne can produce annual N yields of over 700 $kgNha^{-1}$ under dryland (Sinclair et al., 1977) as well as under irrigation (Douglas, 1986). Estimates of nitrogen transfer in lucerne/grass mixtures are few and conflicting depending on the location of the study. Dilz and Mulder (1962) reported that lucerne supplied 8% of the N in the tops of ryegrass during the main growing period in Australia. In Canada, N transferred from lucerne to associated timothy contributed up to 22% (first year) and 30% (second year) of the total N yield of timothy and amounted to up to 13 kg N $ha^{-1}yr^{-1}$ (Ta and Faris, 1987). This transfer increased with progressive cuts and with an increased proportion of lucerne in the mixture. Burity et al. (1989) reported that nitrogen transfer from lucerne to associated grasses contributed 26, 46 and 38% of the total annual N yield of associated grasses during the first, second and third year respectively in North America.

Under most conditions, significant transfer of N will depend upon cycling through grazing animals or on death and decay of legume herbage or roots and nodules (Vallis, 1979). Urine is widely believed to be the major mode of transfer in grazed pastures (Russell, 1961; Whitehead, 1970), the magnitude of transfer being dependent on the percentage of utilisation of the legume forage, distribution of the excreta and the amount of losses through volatilisation. High concentrations of N in urine and dung patches and in stock camping areas, will reduce the proportion of legume in pasture and decrease symbiotic N fixation. Therefore,

the overall response in herbage yield will reflect the balance between the N input from fertiliser application and urine, and its adverse effect upon symbiotic N fixation (Wheeler, 1958).

2.3 ESTABLISHMENT OF LUCERNE/GRASS MIXTURES

One of the major difficulties with lucerne-grass mixtures is in obtaining a balanced establishment of lucerne and grass plants. Either lucerne or grass seedlings are likely to be suppressed depending on the species of grass, seeding rate, timing and method of sowing and nodulation success of lucerne. Seeding rate, sowing method and the rate of nodulation, influence the success of establishing a balanced lucerne-grass mixture.

2.3.1 Seeding rate

Iversen and Calder (1956) recommended a seed mixture of 9 $kgha^{-1}$ of lucerne with 2.2 $kgha^{-1}$ of cocksfoot, 3.4 $kgha^{-1}$ of phalaris and 5 $kgha^{-1}$ of subterrannean clover, based on a study conducted at Lincoln, Canterbury. Baars and Cranston (1977) showed that prairie grass at 13 and 22 $kgha^{-1}$, with 8 $kgha^{-1}$ lucerne, produced higher first year yields than prairie grass sown at 4 $kgha^{-1}$, but in the second and third years, there were no differences. Further work over a four year period by Baars (1980), confirmed that different seeding rates had no effects on prairie grass yield and did not cause significant differences in the yields of lucerne or weed species.

The fast establishment and early suppression of lucerne by Matua prairie grass was reported by several workers (Vartha, 1978; Fraser, 1982,1983; Xu, 1989). Xu (1989) used a very high seeding rate of 32 $kgha^{-1}$ of Matua which led to early dominance of prairie grass and poor establishment of lucerne due to shading and nodulation failure. Fraser (1982, 1983) showed that a seeding rate of 10 $kgha^{-1}$ of Matua prairie grass gave good stand establishment.

In contrast to prairie grass, phalaris sown at 8 $kgha^{-1}$ did not affect lucerne establishment (Xu, 1989). A low seeding rate of 1.5 $kgha^{-1}$ (Fraser, 1982) may have been responsible for the poor competitiveness of phalaris during the first year. The higher seeding rate used by Xu (1989) was effectively lower because 30% of phalaris plants were lost at first

grazing through pulling by sheep. This highlights the need for careful management during the establishment phase of slow growing grasses.

2.3.2 Sowing method

Many researchers have seeded lucerne/grass mixtures in alternate rows rather than drill or broadcast together with the aim of reducing interspecific competition. Smith (1954) recommended this method for establishing lucerne/cocksfoot pastures for light land farming. Cullen (1967) obtained good establishment from mixtures of lucerne, cocksfoot and clover when spring sown in alternate rows spaced 18 cm apart. Lucerne was sown at 10 $kgha^{-1}$ in one row and the mixture of cocksfoot (4.5 $kgha^{-1}$), Montgomery red clover (1.2 $kgha^{-1}$) and NZ white clover (1.2 $kgha^{-1}$) in the alternate row. At Tara Hills, Central Otago, Douglas and Kinder (1973) showed that sowing in alternate rows was successful when lucerne was grown with either ryegrass, phalaris, tall fescue or prairie grass, but not with cocksfoot. In another experiment at the same site, they compared establishment of cocksfoot in either mixed or alternate rows of 18 cm apart, and found that cocksfoot production over the 4 years of the experiment was marginally higher in the mixed rows.

In most New Zealand and overseas studies, alternate rows have been inferior to other methods (Douglas and Kinder, 1973; Tewari and Schmid, 1960; Chamblee and Lovvorrn, 1953; Fyfe and Rogers, 1965). Chamblee and Lovvorn (1953) showed that lucerne/grass mixtures sown in alternate rows produced less total dry matter than broadcast or mixed-in-the-row plots. Where conditions favour lucerne growth, alternate row spacing appears to offer little advantage over straight mixtures and in fact can be a disadvantage, because of the lower yields and greater likelihood of weed infestation. Cullen (1967) reported that under favourable conditions, lucerne tends to dominate the mixture despite the method of sowing and management system adopted but where conditions are wet, lucerne has difficulty in competing with aggressive grasses and weeds.

Xu (1989) cross-drilled lucerne with either prairie grass or phalaris in rows of 15 cm and obtained poor lucerne establishment with prairie grass. Lucerne yield accounted for only 17% of the total pasture yield from lucerne/prairie grass in comparison to 53% in lucerne/phalaris, 144 days after sowing. This very low lucerne yield in lucerne/prairie grass was attributed to slow and poor nodulation which lasted for two years as a result of early

shading by prairie grass. Pritchett and Nelson (1951) showed that shading depressed the weight of roots more than that of the tops and severely affected the number of nodules. Cross-drilling therefore, does not overcome the problem of poor lucerne establishment with fast growing grasses like prairie grass particularly where the grass sowing rate is high.

Over-drilling grasses in to mature stands of lucerne was shown to provide satisfactory establishment of lucerne/grass mixtures (O'Connor 1967; Vartha, 1967, 1973; Baars and Douglas, 1976; McQueen and Baars, 1979). Eston and Stiefel (1982) reported that over-drilling grasses into a three year old lucerne stand in autumn increased total winter and summer yields. The yield of lucerne was not adversely affected by the grass, and the weed component was reduced by over-drilling. Vartha (1967) recommended over-drilling as a particularly suitable method of establishing lucerne/grass mixtures on medium-heavy and heavy soils.

2.4. GRAZING MANAGEMENT OF LUCERNE/GRASS MIXTURES

Grazing management appears to be the key factor in successful maintenance of lucerne/grass mixtures. Langer (1979) commented that even at their simplest, studies on lucerne/grass mixtures have "demonstrated the very real difficulty of correct management to suit one component without at the same time putting stress on the other. Almost invariably, either the lucerne or the grass will have to be cut or grazed at less than optimal stage, and this tends to upset the delicate balance between the two species." Despite this concern, very few studies have been carried out on grazing management of lucerne/grass mixtures.

It is generally understood that lucerne and grasses respond differently to various management practices because they differ markedly both morphologically and physiologically. Likewise, differences exist in development rates to flowering among species of grasses and cultivars of lucerne. The most critical components of the grazing system for lucerne/grass pastures appear to be the frequency of grazing and the duration of grazing (O'Connor, 1967; Brownlee, 1973; Mckeeny 1974).

2.4.1 Grazing frequency

Lucerne grown in mixtures with grass responds to defoliation frequency in essentially the same way as it does when grown in a pure stand (Dotzenko and Ahlgren, 1950). On the other hand, grasses respond differently in pure and in mixed swards with lucerne (Comstock and Law 1948). In pure stands, the productivity of most grass species decreases with increased frequency of clipping. In mixtures with lucerne, the relative yields of grasses may be increased by early or frequent cutting, because lucerne growth and shoots are reduced under these conditions and the lucerne offers less competition.

Vartha (1973) demonstrated that longer spelling periods were beneficial to lucerne in association with grasses where grazing durations were kept short. Frequent grazing increased the percentages of cocksfoot and ryegrass above those recorded when lucerne was at early flowering before grazing. When grazed at early flowering stage, unsown species made a notable contribution to total herbage yield in the first year only, but under frequent grazing, unsown species comprised of 26% and 33% in autumn-winter of the third year. Total herbage yield was higher under early flowering than under frequent grazing particularly in the third year of measurement. However, there is a dilemma in advocating the advantage of early flowering grazing. Both ryegrass and cocksfoot showed poor survival as a result of the conditions favouring rapid lucerne growth, which led to a loss of yield advantage over pure lucerne after the first year. Thus Vartha (1973) concluded that where grazing management was aimed at obtaining maximum yield of lucerne in the warm season, the inclusion of perennial grasses gave no sustained advantage in the cool season. There is a need to seek ways of rapidly changing from summer lucerne dominance to winter grass dominance.

In Britian, Barker *et al.* (1957) compared the effects of several different frequencies of grazings ranging from 3 to 12 grazings per season on a lucerne/cockfoot mixture. They reported that frequent grazing at 4 weekly to 2 weekly intervals encouraged profuse tillering of cocksfoot and led to serious reduction in the proportion of lucerne in the sward.

In warmer climates, although the longer growing season allows more harvests, it is essential to ensure a sufficient interval between harvests. Levels of summer production from lucerne, in particular, will decrease substantially with more frequent cutting (Judd and Radcliffe, 1970). In Canberra, Australia, Moore *et al.* (1946) found that lucerne declined substantially over 4 years when the interval between the grazings was only 3 weeks.

It is generally accepted that increasing severity of defoliation results in reduced pasture yield (Davidson, 1976) as a result of root reserve depletion. Carbohydrate and dry matter accumulation in roots directly reflects the severity and timing of defoliation, with early defoliation being more detrimental to root growth and carbohydrate storage than later harvest (Wolf, 1978). Nielsen and Lysgaard (1956) showed that the percentage of nonstructural carbohydrate in lucerne taproot declined for a period of 20-30 days after defoliation before accumulation began. Lucerne plants grown for 40 days without cutting were found to produce 3.50 g dryweight, more than twice the root yield of 1.40 g from plants cut after 20 days (Steinke, 1963 cited by Langer, 1967).

2.4.2 Grazing duration

Iversen (1967) proposed that lucerne should be grazed "boldly at the early flower stage with 120-500 sheep ha^{-1}, so that the stand was grazed bare in about 4 days then given a 36-day rest." However, this may be difficult to achieve under farm conditions and its necessity can be questioned on the ground that when lucerne is defoliated, there is a lag phase before the new basal shoot becomes vulnerable to grazing (Janson, 1978). The length of this lag phase is strongly influenced by the environmental conditions at the time of defoliation (Leach, 1979) and the stage of maturity at defoliation (Janson, 1975; Leach, 1979). O'Connor (1970) measured the lag phase from partial or whole stem removal until new shoots appeared with open leaves and found that it varied from 3 to 10 days. Janson (1975), concluded from simulated grazing studies, that lucerne in the mid-vegetative and early bud stage could be defoliated over 14 days, with little effect on the regrowth cycle, but at 1% flowering, a 7-day defoliation gave the best regrowth. This was also observed earlier by Keoghan (1970) who found that long grazing durations at mature stages of lucerne growth resulted in decapitation of early fast growing shoots.

There are still very few studies on the effects of grazing duration on lucerne/grass mixtures. O'Connor and Vartha (1968) compared two grazing systems (3-day grazing with 39-day spelling and 14-day grazing with 28-day spelling) on a lucerne/ryegrass pasture. The 14-day grazing with 28-day spelling produced higher herbage yields within four weeks after grazing in spring. Grass production was lower under the 14-day grazing than the 3-day grazing treatment, but the lucerne proportion was increased and weeds were decreased. However, these

observations must be viewed with caution since only one grazing cycle was involved. The results of Xu (1989) indicated that grazing duration treatments of 7 and 14 days have little effect on the lucerne production, but that the production from grasses was considerably increased by the shorter grazing duration. Short grazing consistently increased the production of both phalaris and prairie grass, although not to the same magnitude, because of their different morphological features. Thus, the higher proportion of lucerne reported by Xu (1989) under long grazing was not due to an increase in lucerne from long duration grazing but because of less grass growth. Moreover, the effects of long and short duration treatments were confounded by the unequal length of the interval between grazings. The yield advantage from short grazing duration may thus be due to the longer period of regrowth.

2.4.3 Grazing behaviour

Grazing management has an indirect effect on the productivity and composition of mixed pastures through its influence on animal behaviour such as diet selection, camping and distribution of excreta. Given the opportunity, all grazing animals are selective in their diet. In lucerne/grass mixtures, lucerne is generally selectively grazed in preference to grasses and may therefore result in grass dominance (Watkin and Clements, 1979).

Grazing animals remove only a small quantity of nutrients from the pasture, the remainder being excreted (Davis et al. 1962). Arnold (1981) quantified typical amounts of nutrients returned to pastures per annum in excreta as 100-150 kg Nha^{-1}, 75-125 kg Kha^{-1} and 10-20 kgPha^{-1}, depending on stocking rate, the size and age of animals, and the species and composition of herbage. However, the distribution of nutrients is uneven being concentrated in urine patches and stock camps. Urine patches gain about 400 kg Nha^{-1} and 700 kg Kha^{-1} of which about 60-70% of N and 80-90% of K is freely available (Arnold, 1981). The effect of urine often lasts for 2-4 months depending on the rate of depletion of deposited nutrients (Watkin and Clements, 1978). Urine stimulates grass growth which in turn may reduce legume proportion. In some instances pasture may be 'burned' by the urine in which case selective grazing with concomitant deterioration in botanical composition would occur (Richard and Wolton, 1975). On the other hand, Norman and Green (1958) and Keogh (1973) reported that animals preferred herbage growing from the urine patch provided it did not suffer from urine burn. Soil pH is usually increased by urine and this may change the availability of other nutrients such as manganese and phosphate (Barrow, 1960).

Animals return most of the ingested P, Ca, and Mg in the dung, as well as appreciable quantities of N and K (During and Weeda, 1973). However, dung being largely in an organic form, the nutrients are released relatively slowly and are of limited immediate value to pasture production (Watkin, 1975). Norman and Green (1958) found that increases in pasture yields following application of dung were still apparent after four cuts, while response to urine after the second cuts was negligible.

2.5 EFFECTS OF WATER AVAILABILITY ON PASTURE PLANTS

Water is recognised as the most important factor limiting crop production (Wiersma and Christie, 1987). It is a major constituent of the cell protoplasm and physiological processes in the protoplasm become impeded when a plant becomes dehydrated. Water is involved in the processes of photosynthesis and respiration, and carries out a variety of additional functions; for example it provides a medium for the movement of dissolved substances in the xylem and phloem. It is therefore important to understand the water relations of a crop, and in particular, the effects of drought, to be able to make optimum use of the available soil water. In this section of the review, the effects of water availability on crop canopy development, shoot and root yields, and water use efficiency will be covered.

2.5.1 Canopy development

One of the most important consequences of the sensitivity of cell enlargement to small water deficits is the marked reduction in leaf area, and the resulting reduction in crop growth rate, particularly when there is incomplete light interception. Water stress can affect leaf area by reducing tillering and by hastening the death of leaves and tillers. For example, Perry and Larson (1974) showed in lucerne, that the reduction of soil water to 50% of the field capacity reduced both the number of primary shoots and the regrowth of shoots after defoliation. Water stress reduced both leaf area and leaf extension (Jones *et al.* (1980) and tiller numbers (Korte and Chu, 1983) in field swards of perennial ryegrass. In another study by Parfitt et al. (1985), perennial ryegrass leaf growth was found to decrease from about 5 mmd^{-1} to about 2 mmd^{-1} as the water deficit increased from 70 to 140 mm, in a soil with limiting water deficit of 125 mm, while the growth in the irrigated plots averaged about 7 mmd^{-1} over the same period. The interval between the appearance of new leaves was increased in stressed swards, new leaves appearing more than twice as fast in irrigated swards. The combination of

slower leaf extension and leaf appearance resulted in a marked reduction of leaf area expansion in the stressed swards.

In lucerne, water stress decreases stem number, stem diameter, internode number and length and leaf size (Sheafer *et al.* 1988). Brown and Tanner (1983) reported that with monotonic drying, the development of water stress 2 weeks after cutting, reduced leaflet size and internode length of 'Saranac' lucerne but not the leaf and internode number or stem population. Carter and Sheafer (1983) suggested that although water stress reduced leaf area and yield, the concomitant reduction of stem yield increased the proportion of leaves and thereby improved the digestibility of the herbage.

Lucerne, like perennial ryegrass, recovers rapidly following release from water stress. Cowett and Sprague (1962) reported that when moisture was supplied to drought stressed plants, forage mass and stem numbers were comparable to those of unstressed plants. Sheafer and Barnes (1982) reported that full regrowth following a harvest and rainfall was greater for lucerne which was previously unirrigated and under moisture stress than for irrigated lucerne. Under moisture stress, lucerne tended to have higher root carbohydrate concentrations than well-watered lucerne.

2.5.2 Herbage yield and stand persistence

Numerous reports in the literature show that water deficits decrease crop yields with the degree of reduction varying with severity, duration and timing of the stress. Since leaf expansion is more sensitive to plant water deficit than photosynthesis, pastures whose economic yields consist largely of vegetative growth, are often more sensitive to stress than cereals and grain legumes where the marketable yield is the reproductive growth (Turner and Begg, 1978). Taylor *et al.* (1959) demonstrated that lucerne herbage yield decreased with increasing water stress, whereas seed yield actually increased in plants under a mild stress of -200 kPa to -800 kPa.

Water stress reduces yield through a reduction in the expansion of new leaves, an increase in the death of old leaves and a reduction in tillering. On Ohakea silt loam soils in Manawatu, Korte and Chu (1983) reported that herbage production from perennial ryegrass pasture was markedly reduced by drought. Over a three month period in summer, they

obtained a total herbage yield of 5700 kg $DMha^{-1}$ from irrigated swards compared to only 1800 kg $DMha^{-1}$ from stressed swards. However, on recovery from stress, the average accumulation rate from the previously stressed plots was 53 kg $DMha^{-1}d^{-1}$ compared to 34 kg $DMha^{-1}d^{-1}$ from irrigated swards. Similarly Parfitt *et al* (1985), showed that as pasture growth became limited at a soil water deficit of 125 mm, yields from stressed swards were reduced to half those of the irrigated swards. In Great Britain, Jones *et al.* (1980) reported an overall reduction of 20% dry matter yield from non-irrigated plots.

From pot experiments with 6 grasses (cocksfoot, tall fescue, smooth brome, timothy, perennial ryegrass and reed canarygrass) and 5 legumes (birdsfoot, trefoil, alsike clover, ladino clover, lucerne and red clover) grown at soil moisture levels of 40, 60, 80 and 100% of field capacity, Lee et al. (1974) demonstrated the differences in yield response to soil moisture of different species. All of the grasses except the perennial ryegrass, produced their highest yields at 80% moisture although the tall fescue showed no difference between 60% and 80% moisture. Among the legumes, lucerne yield was highest at 60% while white clover yields were highest at 80%. These differences in growth rate under water stress affect the drought tolerance and competitive ability of the species under dryland conditions (Harris and Lazenby, 1974). In phalaris, root penetration to subsoil moisture and the consequent maintenance of limited activity of the root and lower stem have been suggested as the mechanism whereby the plant survives summer drought and maintains viable axillary buds that can rapidly elongate when stress is relieved (McWilliam, 1968).

Soil and plant moisture status influences autumn dormancy reaction and winter survival of lucerne. In general, moisture stress increases and excess moisture decreases freezing tolerance (Levitt, 1972). Paquin and Mehuys (1980) reported that drought stress and freezing of lucerne on soil at 25% field capacity increased the cold tolerance of unhardened plants by 3.7RC compared to well-watered plants frozen at field capacity.

2.5.3 Nitrogen Fixation

Water deficits depress legume symbiotic N_2 fixation. Survival, multiplication, and movement of the rhizobia responsible for the development of the symbiotic relationship required for N_2 fixation, are reduced by soil water deficits (Sprent, 1976). As a consequence, root hair infection and nodule initiation may be reduced or restricted to sites near the crown. In

general, nodules from plants under moisture stress have the same anatomy as those from well-watered plants, although nodule numbers per plant, nodule mass and nodule size are reduced (Carter and Sheafer, 1983). Nodules subjected to severe water stress resume activity when soil moisture content is restored. Under extreme moisture stress, nodule shedding may occur. Aparicio-Tejo *et al.* (1980) reported that lucerne nitrogenase activity decreased by 85% when plants were subjected to water deficit, but activity recovered to 79% of pre-water deficit rates when turgor was restored. The principal cause of reduced nitrogenase activity under water stress may be the decline in photosynthesis that accompanies drought.

2.5.4 Nutrient Uptake

The yield and persistence of pastures under water stress is also dependent on the nutrient status before and during the water deficit (Colman and Lazenby, 1975). A reduction in the uptake of nitrogen and phosphorus induced by a water deficit is well documented by several authors (Gates, 1957; Storier 1965; Greenway and Klepper, 1969). Greenway et al. (1969) showed that the uptake of phosphorus was reduced slightly when the potential of the root medium was reduced to -200 kPa and decreased linearly as the potential of the root medium was reduced further until, at -1000 kPa, phosphorus uptake was negligible.

Thus, reduced growth observed as a result of moderate water deficits may, in part, arise from a disturbance in mineral nutrition as well as from any direct effects of water deficits on growth. In the field, nutrient levels, are usually highest in the surface soil, which is the first to dry out. This implies that although the plants may have roots penetrating the deeper and wetter parts of the soil profile, the relative lack of nutrients in the subsoil and the lack of available nutrients in the dry surface soil may limit growth and yield more than the soil water deficit *per se*. For example, Garwood and Williams (1967) showed that when the soil surface was dry, injection of nutrients, particularly nitrogen, into a perennial ryegrass sward at a depth of 45 cm resulted in more than double the yield response to that of a similar sward given a surface application of nitrogen. Simpson and Lipsett (1973) observed a similar response in lucerne yields to deep placement of phosphorus under conditions of simulated surface drought. The uptake of several other elements has also been shown to be reduced by water stress (Greenway and Klepper 1969; Gates 1974).

2.5.5 Root growth

As early as 1926, Weaver recognised that keeping the surface soil too moist during the early life of the plant may promote a more shallow rooting habit, and the crop may later suffer from drought, unless watered very frequently. Conversely, delay in time or insufficient irrigation may tend to promote a deeper rooting habit. This theory is widely accepted and confirmed by several researchers working on different crops although in some instances results were contradictory.

Kmoch *et al.* (1957) found that roots developed under limited soil moisture conditions were finer and had more and higher order branches than roots developed under favourable soil moisture conditions. The work of Bennet and Doss (1960) on a number of forage species confirmed those observations although the amount of roots and the depth of rooting varied with species. More recently however, Abdul-Jabba *et al.* (1982) found that the lucerne root mass and yield was highest under high moisture levels and that the shoot/root ratio increased with increasing moisture level. Further work on lucerne by Jodari-Karimi *et al.* (1983) showed that although deeply irrigated lucerne produced more roots in the lower depth, total root production remained similar to that of shallow irrigation.

2.5.6 Water use

Potential evapotranspiration or maximum water use by a crop occurs only when the vapour pressure of the water in the soil and/or at the leaf surface is at saturation (Wiersma and Christie, 1988). Very high rates of evapotranspiration (ET) can be obtained when lucerne is grown on well-watered soil. This is because lucerne has a high stomatal conductance, small leaves with high boundary layer conductances and high stem densities, resulting in high parallel hydraulic conductances and high root densities (Rosenberg and Verma, 1978). Under moisture limiting conditions, dry matter production decreases proportionally to the decrease in transpiration (T) below the maximum that would occur if crops were well supplied with water. This is shown in the relationship:

$$Y/Ym = T/Tm,$$

where Y_m is potential yield when T is equal to the maximum climate-driven transpiration (T_m). At canopy closure, $T \approx ET$.

Very little information on water use of pasture species under New Zealand conditions is available. Tantrum and Mitchell (1972) studied the water loss of a number of crops and pasture species under controlled environmental conditions in growth cabinets. They found that the water loss from lucerne was highest of all the species tested and that of phalaris was higher than all the other grass species. Under field conditions Parfitt *et al.* (1985), showed that the daily water use of a ryegrass sward varied from 1.0 to 3.4 mm depending on season and soil water content. Data on the daily water use of lucerne mainly originates from the USA, where maximum daily water use or ET is reported to be typically 5 to 11 mm although extremes of 1.3 and 14 mmd^{-1} have been reported (Sheafer et al. 1988).

Water use is generally greatest during the warmest months of the year and with full canopy cover. Reduced growth or dormancy induced by temperature, day length, or soil moisture deficits reduces daily potential ET. Water use during daytime hours usually constitutes the largest daily proportion. Rosenberg (1969) reported that in lucerne, nocturnal ET accounted for 21 % of the total daily ET, because of temperature inversion and stored soil heat.

Crops differ in their seasonal use of water because of growth characteristics, date of planting, and so on. A perennial forage crop (for example, lucerne) will begin growth and use water early in the season and will continue through the summer until autumn, whereas an annual, such as maize will begin its growth cycle later in the season and thus have a different seasonal water-use pattern. Generally, the evapotranspiration rate is at its highest in most plants when about 60 to 70% of the growing season has elapsed (Wiersma and Christie, 1987). Seasonal ET rates are influenced primarily by length of growing seasons and temperature (Keller and Carlson, 1967). Seasonal rates for lucerne range from 400 mm in the northeast to 1890 mm in the arid southwest of USA.

2.5.7 Water use efficiency of forage crops

The yield of a crop is measured by the marketable produce per unit area. Crops vary, however, as to the amount of water transpired per unit of photosynthetic product (Wiersma and Christie, 1987). Water use efficiency (WUE) is now commonly defined as yield per unit of ET (Rawson *et al.*; Sheafer *et al.*, 1988). Under an irrigated situation, it can be

described as the yield increase from irrigation (irrigated crop yield minus dryland crop yield) per unit amount of irrigation water applied.

The response of pasture and lucerne to irrigation is well researched in New Zealand (Ritchie, 1978). However, the results are extremely variable as shown by Martin (1984), who reported a range of pasture yield increases from 11% to 81% depending on rainfall over a five year period. In a dry year with 369 mm of rainfall (1980-81), irrigation when moisture content in the top 150 mm had fallen to 16% by weight, increased pasture yield from 7120 to 12860 kg $DMha^{-1}$. Corresponding data for a wet year with 983 mm of rainfall (1979-80) were 10440 and 11610 kg $DMha^{-1}$ respectively for unirrigated and irrigated plots - an increase of only 1170 kg $DMha^{-1}$.

In the USA, Wright (1988) reported a water requirement (ET) of 58.1 mm to produce 1000 $kgha^{-1}$ of lucerne corresponding to a WUE of 17.2 kg $DMha^{-1}mm^{-1}H_2O$. Sammis (1981) concluded from a number of experiments in the United States that 83 mm of water was required to produce 1000 kg of lucerne. Similarly Heichel (1983) summarized research from diverse climates and reported that 56 to 73 mm of water are required to produce 1000 kg $DMha^{-1}$. However, the adoption of any dry matter yield water input function is misleading, since daily and seasonal water use and plant growth are dramatically influenced by climate and cultural practices.

The WUE of C_4 species is generally twice that of C_3 species and this difference increases with temperature over the range 20 - 30^{o}C (Bjorkman, 1971; Ludlow, 1976 cited by Turner and Begg, 1978) and is evident at the leaf, individual plant, and sward level when comparing C4 pasture grasses with C3 legumes (Ludlow, 1976). The higher WUE of C4 species arises from their generally higher photosynthesis and growth rates, particularly under high light and temperature and their higher stomatal resistance (Turner and Begg, 1978).

There is no unique value for the WUE of a species or a plant as it changes with leaf age, environmental conditions, previous history and degree of water stress (Rawson *et al.*, 1977). However, it is important to know the capacity of a species or cultivar to adopt to the environmental conditions and in this context, WUE may provide a useful parameter in assessing this. One of the main ways that the environment influences WUE is by influencing

the boundary layer and stomatal resistance to CO_2 assimilation. Thus water stress increases WUE, but only at the expense of a reduction in the rate of photosynthesis.

The effect of the stage of crop development on WUE is still not clear. Evidence from temperate zone crops or container experiments suggests that there is little effect (Stanhill, 1983). Hanks *et al.* (1978) have shown from experiments with maize that the large reduction in dry matter accumulation caused by water stress at flowering were accompanied by a proportional reduction in ET, so that the WUE was unaffected. However other workers, such as Doorenbos and Kassam (1979) suggested that there is an important effect of crop growth stage during water stress on the WUE.

In addition to the crop species, growth stage, season and location, a number of physiological features of the plants appear to influence WUE. Fuchs (1975) showed that WUE increased with stomatal resistance and leaf area index, and that plants with vertically arranged leaves have lower WUE values than those with horizontally or randomly arranged leaves.

Cultural practices such as weed control, timing of harvest in relation to irrigation, and minimisation of surface runoff, soil evaporation and deep perlocation provide a higher proportion of applied water for use in transpiration and thereby increase WUE.

2.6 EFFECT OF SOIL DEPTH

Several soil series and soil types in New Zealand are distinguished on the basis of depth of fine textured material over gravels. In regions like Canterbury where soil moisture deficits occur in most seasons, it is expected that soils with greater depths of fine material (and therefore higher water-holding capacities) should support crops with higher yields than soils with lesser depths. Bennet *et al.* (1980) found that the depth of fine textured material over gravels is positively corelated to the yields of spring-sown barley under dryland conditions.

Webb and Purves (1983) compared the effects of three different soils on yield of autumn-sown wheat and oats within a single paddock. Six plots were located on each of the soils for each crop. The relative yield of oats from deep Templeton soils, moderately deep to deep Wakanui soils, and shallow Eyre soils were 2.0, 2.1, and 1.0 respectively, and of wheat were 2.1, 1.6, and 1.0 respectively. A strong correlation between yields of both crops and soil

depth were obtained. The main reason for this correlation was considered to be due to the correlation between plant-available water-holding-capacity and soil depth. Deeper soils with higher plant-available water storage would have resulted in the plants sufferring a shorter period of stress than in shallower soils, and therefore produce higher grain yields. However, in extremely dry conditions when plants are stressed from early spring, soil depth may be less important as crops on all soils will be severely stressed and yield will be low.

Sherrel (1987) used soil depth as a covariate in the analysis of total water use from sowing until harvest, and found water use by lentils in the shallowest plots (49 cm) similar to water use by plants in deeper plots (80 cm). He concluded that soil depth was unimportant in determining water use under well watered conditions.

Hayman and Stocker (1982) compared the soil water extraction patterns under pasture and lucerne on Eyre stony silt loam and Wakanui clay loam soils. They found that on the stony Eyre soil, 38% of the deficit under pasture and 58% of the deficit under lucerne came from below 0.3 m on the driest measured profiles; and 32% and 40% of the deficit under pasture and lucerne respectively, came from the gravel sub-strata on the driest measured profiles. This indicated that the effective rooting depth on stony soils is not confined to the gravel-free profile. However, lucerne tends to withdraw water uniformly from the first 1.5 m over a range of soil water deficits, but pasture species tend to withdraw water initially from the upper part of their rooting zone.

Jamieson (1985) investigated the soil moisture extraction patterns from irrigated and dryland arable crops in Canterbury, on a Templeton silt loam soil. He found that crops were capable of extracting water from depths of at least a metre when they need to, under dryland conditions, but under irrigation, crops will extract water from nearer the surface where it is most easily available. Parfitt *et al.* (1985) working on a deep allophanic volcanic ash soil in the North Island showed that water extraction by pasture occurred to a depth of about 1.8 m and that at a water deficit of 125 mm, 50% of the water had been extracted from the top 0.25 m of the soil.

Specific data on the performance of prairie grass and phalaris on dryland shallow soils are lacking, although it is widely acknowledged that both these grasses have potential for dryland production (Hume and Fraser, 1985).

CHAPTER 3

EFFECTS OF GRAZING DURATION ON LUCERNE AND LUCERNE/GRASS MIXTURES

3.1 INTRODUCTION

Past studies on grazing management of lucerne/grass mixtures were of a short term nature, involving only a few grazing cycles (O'Connor and Vartha 1968; Xu, 1989). Hence the validity of their results could be questioned on the grounds that they do not account for the difference in regrowth period between grazings, or for the long term effects of the treatments on variates such as root reserve depletion. This part of the research was, therefore, a continuation of the investigation of grazing duration studies initiated by Xu (1989).

The aim of this ongoing trial was to compare the sociability of prairie grass and phalaris as companion species for lucerne and identify an appropriate grazing duration regime to obtain maximum benefits from lucerne/grass associations. Therefore the objectives of this study were:

1) to compare the the productivity of pure lucerne with lucerne/prairie grass and lucerne/phalaris mixtures; and

2) to compare the effects of short grazing duration against long grazing duration on the productivity and composition of lucerne/prairie grass and lucerne/phalaris mixtures.

3.2 MATERIALS AND METHODS

3.2.1 Location and soil

The trial was located on Lincoln University Research Paddock No.D2. The soil of the experimental area was a Templeton fine sandy loam (N.Z. Soil Bureau, 1967) consisting of three distinct layers. The texture of the upper 25 to 30 cm of the profile varied from fine sandy

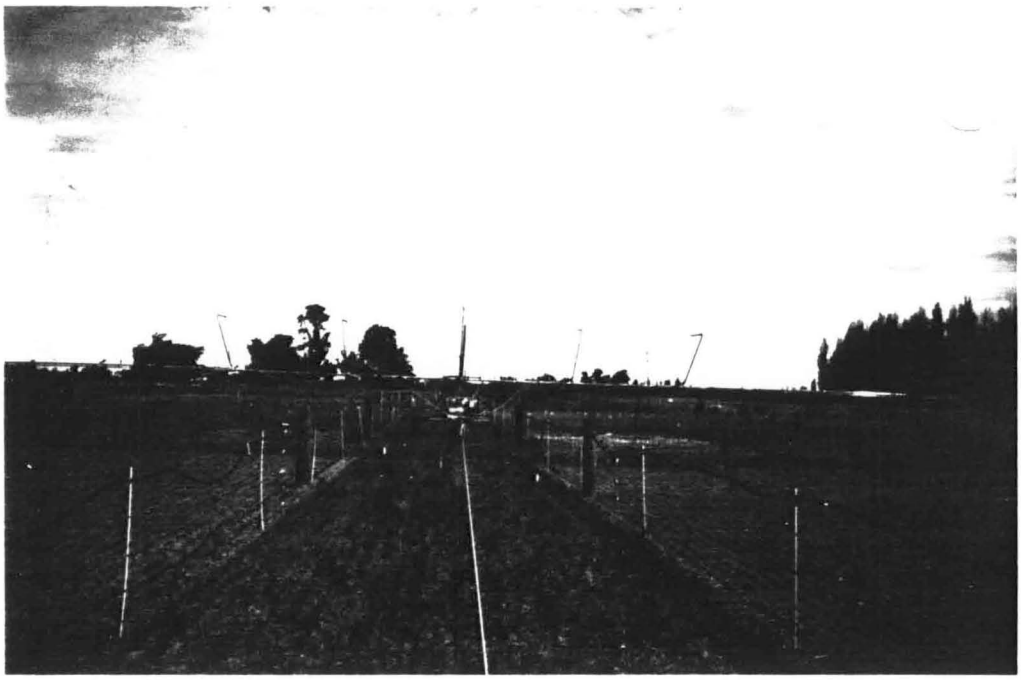


Plate 1: Irrigation in progress (22/1/89) with the mini-boom irrigator.

loam to sand. Short range spatial variability in texture and depth to gravel was high, with sand lens inclusions, which implies short range variations in available water. The total depth of the profile to the gravel ranged between 40 and 130 cm.

Results of chemical analyses on soil samples taken in May 1988 are shown in Table 3.1.

Table 3.1 MAF quick test soil chemical analysis results from the experimental site.

pH	Ca	Mg	K	Na	P	S
5.9	5	20	12	8	16	12

The tests indicate that the soil was marginally acidic and that according to the classification of McLaren and Cameron (1990), the status of P and S was medium, whilst that of Mg and K was high. The field capacity of the soil ranged from 117 mm at 40 cm depth to 280 mm at 130 cm. No drainage was assumed to have occurred at the site during the period of study.

3.2.2 Climate

The 1988/1989 period was extremely dry with annual rainfall well below average (Table 3.2). Rainfall from June 1988 to March 1989 was only 270 mm, less than half of the long term mean of 568 mm for the same period. Only in the winter of 1989, was the mean rainfall comparable to the long term mean. Overall temperature means for the entire period were higher than average with high solar radiation receipts over the summer months. Mean vapour pressure deficit (VPD) and potential evapotranspiration (ETp, Penman's) exceeded the long term averages from July 1988 through to March 1989 with VPD values nearly twice those of the long term means in October and December 1988. The mean wind run (kmd^{-1}) over the period was consistently higher than the long term means.

Month		Rainfall (mm)		Mean Temp. (°C)		Mean Max. Temp. (°C)		Mean Min. Temp. (°C)		Mean Solar Rad $MJm^{-2}day^{-1}$		Mean VPD at Mean T (kPa)		Penman ET_p (mm/month)		Mean Wind run (km/day)	
1988	June	32	(61)	6.6	(6.2)	12.1	(10.7)	1.2	(1.9)	4.1	(5.5)	0.22	(0.22)	31	(36)	290	(199)
	July	25	(68)	7.6	(5.7)	12.6	(10.1)	2.6	(1.4)	4.1	(6.3)	0.29	(0.23)	42	(41)	313	(213)
	Aug	35	(62)	8.1	(6.7)	13.8	(11.4)	2.4	(2.7)	8.5	(9.6)	0.34	(0.24)	67	(57)	359	(248)
	Sep	7	(47)	11.2	(9.4)	16.8	(14.2)	5.5	(4.6)	12.9	(13.6)	0.37	(0.27)	82	(74)	354	(266)
	Oct	7	(49)	14.0	(11.7)	20.7	(16.8)	7.3	(6.7)	17.8	(18.0)	0.66	(0.35)	148	(103)	505	(284)
	Nov	30	(53)	15.1	(13.6)	20.7	(18.8)	9.5	(8.1)	21.2	(20.6)	0.55	(0.44)	141	(121)	437	(289)
	Dec	23	(57)	18.0	(15.4)	24.0	(24.0)	12.1	(10.4)	25.6	(21.0)	0.77	(0.48)	189	(136)	477	(285)
1989	Jan	59	(60)	18.2	(16.4)	23.6	(21.3)	12.9	(11.5)	22.5	(21.5)	0.66	(0.63)	157	(146)	414	(304)
	Feb	34	(54)	16.4	(16.2)	20.7	(20.9)	12.0	(11.9)	19.1	(19.4)	0.54	(0.55)	119	(118)	396	(288)
	Mar	18	(57)	16.1	(14.6)	22.0	(19.2)	10.2	(9.9)	15.0	(17.4)	0.58	(0.45)	116	(98)	389	(246)
	Apr	72	(56)	11.9	(12.0)	17.6	(16.7)	6.1	(7.4)	10.6	(11.4)	0.26	(0.29)	61	(66)	290	(222)
	May	92	(71)	9.2	(8.7)	12.8	(13.3)	5.5	(4.2)	4.9	(7.3)	0.17	(0.26)	55	(49)	307	(225)
	June	52	(61)	7.3	(6.2)	11.9	(10.7)	2.8	(1.9)	4.6	(5.5)	0.25	(0.22)	62	(36)	325	(199)
	July	50	(68)	5.4	(5.7)	20.2	(10.1)	0.6	(1.4)	6.1	(6.3)	0.19	(0.23)	38	(41)	293	(213)
	Aug	47	(62)	8.3	(6.7)	11.8	(11.4)	4.7	(2.7)	6.6	(9.6)	0.21	(0.24)	43	(57)	327	(248)
	Sep	27	(47)	10.1	(9.4)	13.9	(14.2)	6.2	(4.6)	11.5	(13.6)	0.20	(0.23)	60	(74)	353	(266)

Table 3.2 Meteorological data for the period from June 1988 to September 1989 and long term means for the months at Lincoln, Canterbury.

Note: The figures in brackets are long term means. All means except rainfall are for the period 1976-1986. Rainfall means are for 1930-1981 (Source: Plant Sci. Rev. of Res. Vol 4, 1987-88).

Plate 2: A lucerne/phalaris plot immediately before grazing (9/11/89).

3.2.3 Irrigation

The extreme drought conditions during spring and summer 1988/89 which followed the very dry 1987/88 season made it necessary to apply a limited amount of irrigation to ensure the survival of the plants. A total of 150 mm of water was applied on three occasions: 60 mm each in December 1988 and February 1989 and 30 mm in March 1989. A travelling gun irrigator was used for the first event and a miniboom (Plate 1) was used for the last two irrigations. The irrigation was variable as a result of wind drift and stoppages due to mechanical problems.

3.2.4 Trial design and treatments

The trial design was a randomised complete block with a factorial combination of three pasture types and two grazing durations, replicated four times (Table 3.3). The trial layout is shown in Appendix I which includes spare plots of lucerne under short or long grazing.

Table 3.3 Treatments of the lucerne/grass mixture grazing experiment

Pasture mixture	Grazing duration
Lucerne (*Medicago sativa* L.) cv.WL320	Short (3-7 days)
	Long (6-14 days)
Lucerne/prairie grass (*Bromus willdenowii* Kunth) cv"Grasslands Matua"	Short (3-7 days)
	Long (6-14 days)
Lucerne/phalaris (*Phalaris aquatica* L.) cv."Grasslands Maru"	Short (3-7 days)
	Long (6-14 days)

3.2.5 Establishment and first-year management

The paddock was ploughed in March 1986 and again in October 1986 after applying 5t ha^{-1} of lime in May 1986. It was then cultivated, rolled and harrowed immediately before drilling. Seeds were drilled between November 4-7, 1986. The grasses were drilled in an east-west direction at 15 cm row spacings. Lucerne was then cross-drilled at the same row spacing over the grass strips. Lucerne seeds were inoculated and pelleted before sowing.

a

b

Plate 3: Pure lucerne plots four days after start of grazing (7/5/89): a) short duration and b) long duration grazings.

Germination rates, thousand-seed weights and sowing rates of the lucerne and grasses are shown in Table 3.4.

Table 3.4 Germination rate, thousand seed weights and sowing rates of lucerne, prairie and phalaris.

Species	Germination (%)	1000 Seed-wt (g)	Sowing rate ($kgha^{-1}$)
Lucerne	96	3.08	7.5
Prairie grass	61	11.15	32.0
Phalaris	64	1.57	8.0

Herbicide 2-4DB was applied at 3.2 kg $a.i.ha^{-1}$ (8*l* product/ha) for weed control on December 16, 1986 and insecticide Lorsban (chlorpyrifos) was applied at 0.6 kg $a.i.ha^{-1}$ (1.5*l* product/ha) for sitona weevil control on June 8, 1987. No fertilizers were applied either before or after sowing.

Table. 3.5 Grazing dates and durations from January 1987 to April 1988.

Short duration		Long duration	
Grazing period (date)	Grazing duration (days)	Grazing period dates)	Grazing duration (days)
01/04 - 07/04/87	6	01/04 - 15/04/87	14
31/07 - 07/08/87	7	31/07 - 14/08/87	14
20/10 - 27/10/87	7	20/10 - 02/11/87	14
01/12 - 04/12/87	3	04/12 - 10/12/87	6
18/01 - 24/01/88	6	18/01 - 30/01/88	12
08/04 - 12/04/88	4	08/04 - 15/04/88	8

Irrigation was carried out in December 1986 (25 mm) and in January 1987 (40 mm). A light grazing was carrried out from 25 January to 31 January to utilise the fast establishing prairie grass before the plots were fenced. The number and duration of grazings before the start of the present data collection period is presented in Table 3.5.

3.2.6 Grazing Management 1988-89

The trial was grazed by sheep six times between April 1988 and September 1989. Grazing was carried out whenever lucerne was at 15-20% flowering stage (Plate 2) except in September 1988, March and September 1989 when the lucerne was in vegetative stage. The plots were visually assessed for dry matter yields, which were cross-checked with estimates from quadrat cuttings, to determine the grazing duration and the number of sheep required to eat available herbage in the prescribed time. Since sufficient numbers of sheep were not always available, Replicates I and II were grazed at different times to Replicates III and IV (Table 3.6).

Table 3.6 Grazing dates and durations from April 1988 to September 1989.

	Rep.No.	Short duration		Long duration	
		Grazing period (dates)	Grazing duration (days)	Grazing period (dates)	Grazing duration (days)
1	I&II	09/09 - 13/09/88	4	02/09 - 10/09/88	8
	III&IV	02/09 - 06/09/88	4	02/09 - 10/09/88	8
2	I&II	14/11 - 18/11/88	4	10/11 - 18/11/88	8
	III&IV	10/11 - 14/11/88	4	10/11 - 18/11/88	8
3	I&II	13/01 - 16/01/89	3	13/01 - 19/01/89	6
	III&IV	06/01 - 09/01/89	3	06/01 - 12/01/89	6
4	I&II	08/03 - 13/03/89	5	02/03 - 13/03/89	11
	III&IV	02/03 - 07/03/89	5	02/03 - 13/03/89	11
5	I&II	05/05 - 11/05/89	6	28/04 - 11/05/89	13
	III&IV	16/05 - 22/05/89	6	11/05 - 22/05/89	11
6	I&II	08/09 - 13/09/89	5	08/09 - 19/09/89	11
	III&IV	19/09 - 26/09/89	7	19/09 - 02/10/89	13

a

b

Plate 4: Lucerne/prairie grass plots four days after start of grazing (7/5/89): a) short duration and b) long duration grazings.

a

b

Plate 5: Lucerne/phalaris plots four days after start of grazing (7/5/89): a) short duration and b) long duration grazings.

Sheep numbers in each plot were adjusted two to three days before stipulated finishing of grazing, to match with the feed availability and consumption rate, in order to achieve uniform residual herbage mass within the predetermined grazing duration. At all grazing events, the number of grazing days under long duration treatments were maintained at twice that of short grazing duration. Plates 3-5 show the short and long grazing duration treatments on pure lucerne, lucerne/prairie grass and lucerne/phalaris after four days of grazing in May 1989. The plots were grazed down to residual dry matters which ranged from 300 kg $DMha^{-1}$ in November 1988 to 700 kg $DMha^{-1}$ in September 1989.

3.2.7 Pasture measurements

The plots were visually assessed immediately before grazing and two 0.2 m^2 quadrat cuts were taken from areas most representative of the mean visual estimates of dry matter yields. Urine patches, stock camps and completely grass or lucerne dominant spots were avoided. The samples were pooled together and then sub-sampled for determination of dry matter content and botanical composition using the standard method of Boswell (1982). The sub-sample for botanical composition was separated into lucerne, grass and weed components.

3.2.8 Statistical analysis

Analysis of variance was conducted on total dry matter production, dry matter production from lucerne, grass, dead material and weed components in the mixtures using the SAS package (Version 5.16, SAS Institute Ltd, 1987). Least significant differences (LSD P=0.05), coefficients of variation (CV%) and probability values (P) for significant interactions are presented in the result tables.

3.3 RESULTS

3.3.1 Total dry matter yields

There were no differences in total dry matter yields for the April 1988 - September 1989 period between the pastures but grazing duration had a significant effect (Table 3.7). Short grazing duration produced a total of 15220 kg $DMha^{-1}$, which was significantly higher than the 13240 kg $DMha^{-1}$ produced under long duration grazing.

Table 3.7 The effect of pasture type and grazing duration on total yields at different grazing dates (kg $DMha^{-1}$).

	GRAZING DATE						
	Sep'88	Nov'88	Jan'89	Mar'89	May'89	Sep'89	Total
Pasture type							
Lucerne	2200	2340	2260	2670	1710	2990	14160
Lucerne/prairie	2380	2770	1850	2580	1880	2900	14360
Lucerne/phalaris	2420	2100	2080	2560	1810	3220	14180
LSD(P=0.05)	307	537	657	734	389	429	1098
Grazing duration							
Short	2570	2540	1930	2930	1970	3290	15220
Long	2100	2260	2200	2280	1630	2790	13240
LSD (P=0.05)	251	439	537	599	317	350	896
Interaction (P)	0.1	0.9	0.9	0.3	0.01	0.09	0.5
CV%	12	21	30	26	20	13	7

The analysis of seasonal DM yields showed that in November 1988, lucerne/prairie grass was significantly higher yielding than both pure lucerne and lucerne/phalaris. In May 1989 lucerne/prairie grass under short duration grazing produced 1040 kg $DMha^{-1}$ (75%) more than under long duration whereas the DM yields of pure lucerne and lucerne/phalaris were similar under both durations (Table 3.8). In contrast, grazing duration had no effect on the lucerne/prairie grass yields of the following harvest in September 1989 but short duration grazing gave 36% and 20% more yields from pure lucerne and lucerne/phalaris.

Table 3.8 The interactions of pasture type and grazing duration on total yields (kg $DMha^{-1}$)

PASTURE TYPE	GRAZING DATE					
	Mar '89		May '89		Sep '89	
	Short	Long	Short	Long	Short	Long
Lucerne	3240	2100	1700	1720	3450	2530
Lucerne/prairie	2630	2540	2400	1360	2900	2910
Lucerne/phalaris	2910	2210	1820	1800	3510	2920
LSD (P=0.05)	1037		550		606	
Significance (P)	0.3		0.01		0.09	
CV%	27		20		13	

3.3.2 Lucerne dry matter yields

The total lucerne yield from pure lucerne of 13430 kg $DMha^{-1}$ was significantly higher than lucerne/phalaris (11610 kg) and over twice that of lucerne/prairie grass which produced only 5860 kg $DMha^{-1}$ (Table 3.9). Although pure lucerne produced more lucerne dry matter than both the mixtures at all harvests, differences between pure lucerne and lucerne/phalaris pastures were significant only in September 1988 and November 1988. The lucerne production from lucerne/prairie grass was significantly lower than both pure lucerne and lucerne/phalaris throughout the entire period. The range of lucerne DM yields in the lucerne/prairie grass was 360 kg $DMha^{-1}$ in September 1988 to 1830 kg $DMha^{-1}$ in March 1989, whereas in the lucerne/phalaris , the range was 1510 kg $DMha^{-1}$ in August 1988 to 2450 kg$DMha^{-1}$ in March 1989.

Grazing duration did not affect the lucerne dry matter production at any harvests (Table 3.9). However there was a general trend that short duration grazing favoured lucerne

production. Total lucerne production from short grazing was 10760 kg DMha^{-1}, 930 kg more than the 9830 kg DMha^{-1} produced from long grazing.

Figure 3.1. shows the effects of grazing duration on the proportion of lucerne as a percentage of total dry matter yields. The proportion of lucerne dropped rapidly in the lucerne/prairie grass towards winter but in the lucerne/phalaris, lucerne remained above 70% under both grazing durations from spring 1988 onwards. Over the entire period of the experiment, the proportion of lucerne was was considerably higher in lucerne/phalaris than in lucerne/prairie grass.

Table 3.9 The effect of pasture type and grazing duration on lucerne yields at different grazing dates (kg DMha^{-1})

	GRAZING DATE						
	Sep'88	Nov'88	Jan'89	Mar'89	May'89	Sep'89	Total
Pasture type							
Lucerne	1870	2310	2260	2670	1710	2600	13430
Lucerne/prairie	360	570	1030	1830	910	1180	5860
Lucerne/phalaris	1510	1580	2040	2450	1670	2360	11610
LSD(P=0.05)	248	535	500	760	340	470	1230
Grazing duration							
Short	1350	1500	1640	2520	1550	2210	10760
Long	1150	1470	1910	2110	1300	1880	9830
LSD(P=0.05)	203	270	408	620	278	384	1004
Interactions (P)	0.02	0.6	0.9	0.08	0.06	0.1	0.06
CV%	18	34	26	31	22	21	11

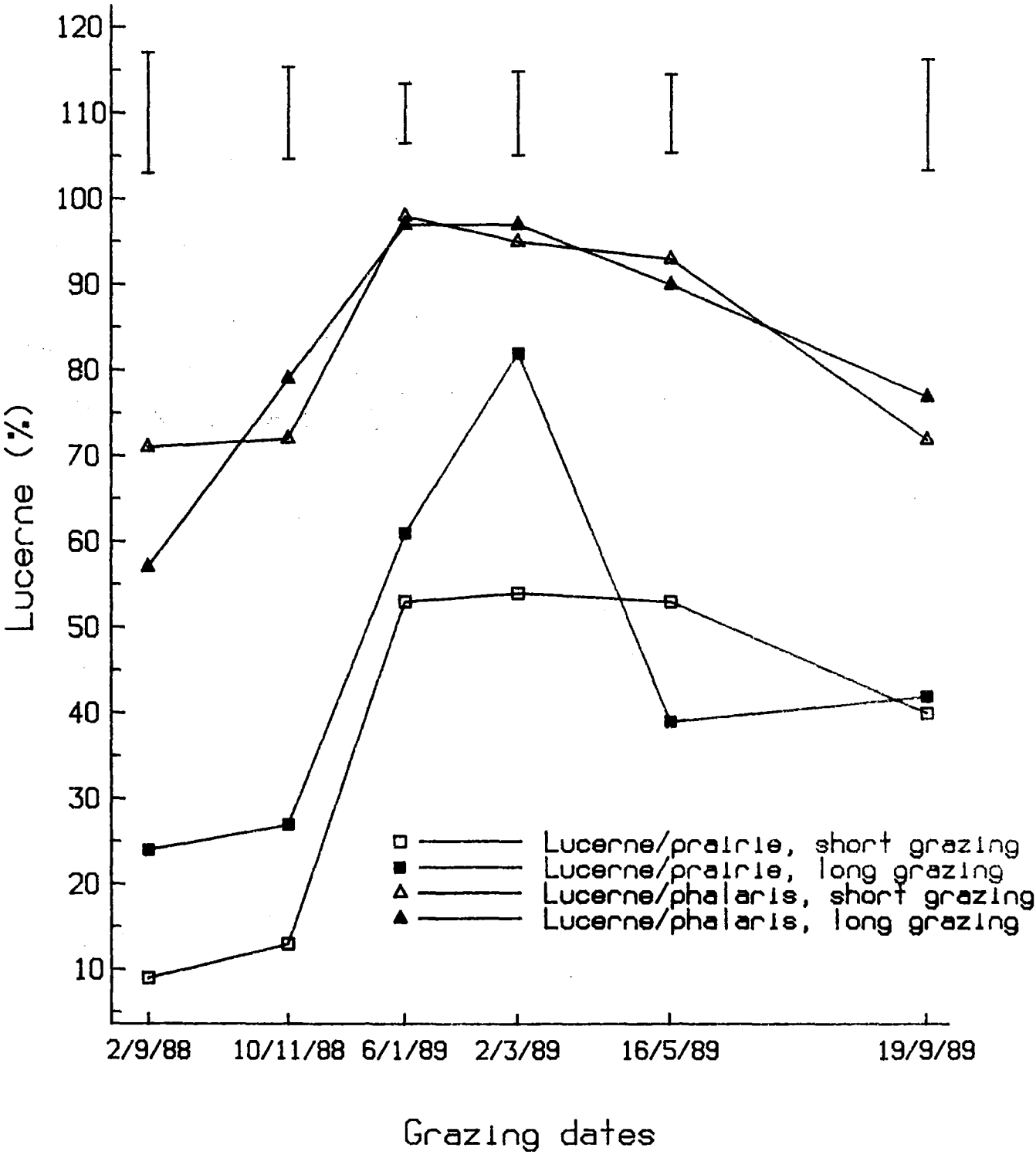


Figure 3.1. The effect of grazing duration on the proportion of lucerne (% of total yield) in lucerne/prairie grass and lucerne/phalaris mixtures at different grazing dates (Bars = S.E.M.)

The significant interaction between pasture type and grazing duration in September 1988 showed that short grazing produced 2070 kg DMha^{-1} lucerne in pure lucerne pastures compared to 1680 kg DMha^{-1} from long duration (Table 3.10). A similar effect was shown on lucerne/phalaris, with yields of 1730 kg DMha^{-1} and 1300 kg DMha^{-1} respectively for short and long duration grazings. On the other hand lucerne yield in the lucerne/prairie grass dropped by nearly 50% (from 470 to 250 kg DMha^{-1}) under short grazing.

Table 3.10 The interaction of pasture type and grazing duration on lucerne yields in September 1988 (kg DMha^{-1}).

PASTURE TYPE	GRAZING DURATION	
	Short	Long
Lucerne	2070	1680
Lucerne/prairie	240	470
Lucerne/phalaris	1730	1300
LSD (P=0.05)	500	
Significance (P)	0.02	
CV%	18	

3.3.3 Grass dry matter yields

Prairie grass was consistently higher yielding than phalaris throughout the trial period producing a total yield of 7950 kg DMha^{-1} compared to only 2440 kg DMha^{-1} by phalaris (Table 3.11). Both grasses declined in production towards summer with phalaris becoming almost completely dormant during the 1988/89 summer. Prairie grass production ranged from a minimum of 750 kg in March 1989 to 2200 kg DMha^{-1} in November 1988, while phalaris production ranged from a minimum of 50 kg in January 1989 harvest to 830 kg DMha^{-1} in September 1988.

Table 3.11 The effect of pasture type and grazing duration on grass yields at different grazing dates (kg $DMha^{-1}$)

	GRAZING DATE						
	Sep'88	Nov'88	Jan'89	Mar'89	May'89	Sep'89	Total
Pasture type							
Lucerne/prairie	1500	2200	820	750	972	1700	7950
Lucerne/phalaris	830	510	50	110	140	800	2440
LSD(P=0.05)	379	330	292	242	208	495	1129
Grazing duration							
Short	850	1030	290	410	420	900	3910
Long	700	780	290	170	330	760	3020
LSD(P=0.05)	112	270	238	197	169	405	600
Interaction (P)	0.01	0.23	0.96	0.02	0.18	0.76	0.05
CV%	46	34	96	79	53	56	20

Total grass yield under short duration grazing was 3910 kg $DMha^{-1}$ which was significantly higher than the 3020 kg $DMha^{-1}$ produced under the long duration grazing. This was mainly due to the higher grass production under short grazing in September 1988 and March 1989 harvests. There were no significant differences at any other grazing dates. The total production from prairie grass under short grazing was 2415 kg $DMha^{-1}$ more than under long grazing but phalaris production was similar at 2570 and 2320 kg $DMha^{-1}$ respectively for short and long duration grazings (Table 3.12). Significant interactions in September 1988 and March 1989 showed that short grazing produced more prairie grass in March 1989 harvest than long grazing, but reduced phalaris yields in both harvests. Prairie grass production was significantly higher than phalaris under short grazing at both harvests but not different under the long grazing treatment.

The changes in the proportion of grasses in the total dry matter production over the different harvesting dates are shown in Appendix 2. A rapid increase towards both spring and winter and decline in summer were observed in both grasses under both grazing treatments.

Long grazing duration resulted in a steep decline in the proportion of prairie grass from 70% in November 1988 to 15% in March 1989. Grazing duration had no effect on the percentage of phalaris in the lucerne/phalaris pasture.

Table 3.12 The interactions of pasture type and grazing duration on grass yields (kg $DMha^{-1}$).

PASTURE TYPE	GRAZING DURATION					
	Sep '88		Mar '89		Total (all harvests)	
	Short	Long	Short	Long	short	long
Lucerne/prairie	1190	1110	1080	430	9160	6740
Lucerne/phalaris	670	1000	150	670	2570	2320
LSD (P=0.05)	336		342		495	
Significance (P)	0.01		0.02		0.05	
CV%	46		80		20	

3.3.4 Weed and dead material yields

Pure lucerne produced weed yields of 170 kg and 390 kg $DMha^{-1}$ respectively during winter 1988 and 1989 (Table 3.13). There were no significant differences in weed yields between the two mixtures. Weed production was not affected by the grazing duration treatments.

Table 3.13 The effects of pasture type and grazing duration on weed yields at different grazing dates (kg DMha^{-1})

	GRAZING DATE	
	Sep '88	Sep' 89
Pasture type		
Lucerne	170	390
Lucerne/prairie	10	20
Lucerne/phalaris	40	60
LSD(P=0.05)	14	116
Grazing duration		
Short	90	180
Long	40	140
LSD(P=0.05)	112	95
Interactions (P)	0.25	0.43
CV%	203	70

All three pastures produced significant amounts of dead material in the harvests of January and March 1989. Pure lucerne produced higher total dead lucerne yields (210 kg DMha^{-1}) than either lucerne/prairie (120 kg) or lucerne/phalaris (170 kg). Grazing duration had no effect on dead lucerne yield. Lucerne/prairie grass had higher dead grass yield (130 kg DMha^{-1}) than lucerne/phalaris (30 kg DMha^{-1}). Short grazing duration resulted in a dead grass yield of 80 kg DMha^{-1} compared to 30 kg DMha^{-1} under long grazing.

3.4 DISCUSSION

3.4.1 Dry matter production and botanical composition

This trial investigated the hypothesis that short grazing duration will favour grass growth while long duration will favour lucerne growth. Grasses recover rapidly following defoliation but lucerne undergoes a lag phase before initiating basal shoot growth. Thus, under

short grazing, lucerne will be supressed through shading by the grasses. Conversely, long grazing duration would allow the lucerne to resume regrowth earlier following removal of stock, since it would have already completed a part of the lag phase during the grazing period itself. This may lead to lucerne dominance of fast growing grasses like prairie grass since their new growth will be grazed before the lucerne basal shoots emerge and become susceptible to grazing.

The data from this experiment only partially supported this hypothesis, since long grazing decreased grass production, but did not increase lucerne production compared with short grazing. Total lucerne and grass yields were higher under short grazing by 9 and 29% respectively than under long duration (Table 3.9 and 3.11). Xu (1989) obtained remarkably similar results (8% more lucerne and 28% more grass under short grazing) from earlier work at the same site.

The different responses by the lucerne/prairie grass and the lucerne/phalaris pastures in this trial demonstrated that the grazing duration effects cannot be generalised for all lucerne/grass combinations, but are dependent upon the grass species used. Short grazing produced 36% more prairie grass and reduced lucerne yields by 11% in the lucerne/prairie grass. In contrast, grazing duration had no effect on phalaris yields, but lucerne yields were 11% higher under short grazing in the lucerne/phalaris. Similar trend was observed by Xu (1989) during the 1987/88 season.

Despite the different effects of grazing duration on the lucerne and grass components of lucerne/prairie grass and lucerne/phalaris, total dry matter yields were consistently higher under short grazing than long grazing. This occurred throughout the duration of this trial as well as during the 1987/88 season reported by Xu (1989) (Figure 3.2a). Greater production under short grazing was due to the enhanced growth of prairie grass in the lucerne/prairie grass and of lucerne in the lucerne/phalaris. Thus it appears that short grazing duration is superior to long grazing duration for both mixtures in terms of total pasture production. This contradicts the conclusions drawn by Xu (1989) who suggested that long grazing duration is better for lucerne/prairie grass, based on the higher proportion of lucerne in the total yield. He failed to appreciate that the lower grass yields under long duration grazing were not accompanied by actual increases in the lucerne yields, or conversely, that higher grass production under short grazing did not result in lower lucerne yields.

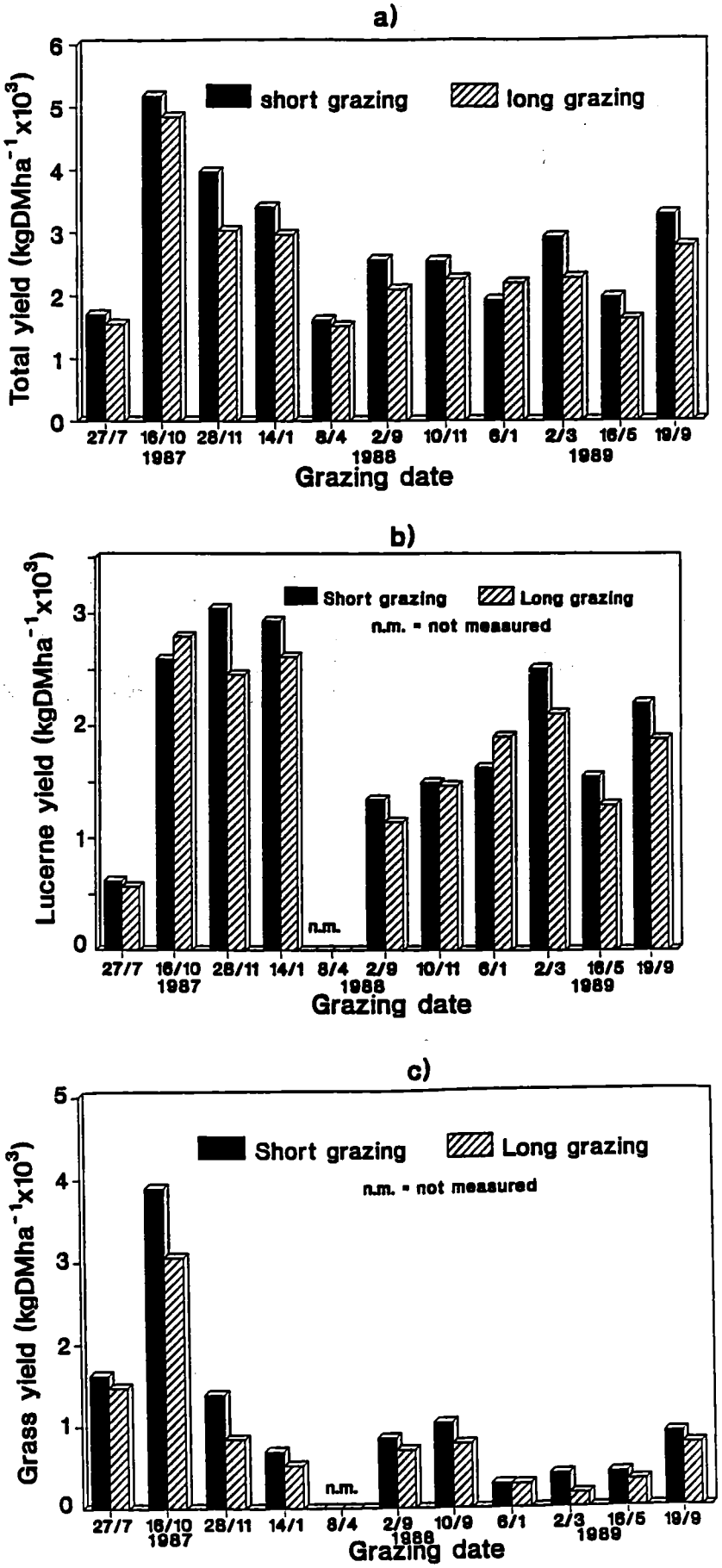


Figure 3.2 The main effects of grazing duration treatments on a) total yield, b) lucerne yield and c) grass yields of lucerne grass mixtures (kgDMha^{-1}).

Xu (1989) obtained further evidence to support the favourable effects of long grazing duration on lucerne/grass mixtures from measurements of lucerne regrowth in October 1988. He found that the regrowth rates of lucerne in both lucerne/prairie grass and lucerne/phalaris were higher (4.5 and 11.5 $gm^{-2}d^{-1}$) under long duration treatment than under short duration (3.2 and 10.9 $gm^{-2}d^{-1}$), 21 days after grazing. Lucerne shoot numbers in lucerne/prairie grass were also higher under long grazing. However, these measurements were made on only one occasion, following a period of high winter grass growth, which would have initially depressed lucerne regrowth under short grazing. Thus the regrowth period of 21 days may not have been sufficient to allow the short grazing lucerne to make a full recovery. There is clearly a need to engage in further studies on recovery rates of lucerne as well as the grasses. The study of Brown (1989) on the regrowth in March 1989 in this experiment showed that both lucerne and the two grasses gave higher shoot lengths in the short grazing duration treatment 44 days after grazing. However, this was also carried out at the end of a severe drought period of summer 1988/89 and the results may have been atypical.

Earlier O'Connor and Vartha (1968) compared two grazing systems (3 day grazing with 39 day spelling and 14 day grazing with 28 day spelling) on a lucerne/ryegrass pasture and found that the latter system of 14 day grazing with 28 day spelling produced higher dry matter yields four weeks after grazing. Grass and weed yields were reduced and lucerne production was increased under the long duration grazing. In this trial, while it can be assumed that long grazing, because it suppressed grass growth, created a favourable condition for lucerne growth, this was not reflected with actual increases in lucerne yields. In fact short grazing produced marginally higher lucerne as well as grass yields (Figure 3.2b and 3.2c). However, O'Connor and Vartha's (1968) trial was carried out over one grazing cycle only and may not have reflected the cumulative effects of the grazing duration treatments on root carbohydrate reserves or the interaction between seasons and grazing duration regimes.

The superior performance of lucerne under short grazing in this trial contradicts the work of several authors (O'Connor, 1967, 1970; Mckinney, 1974; Janson, 1975; and Cosgrove, 1978) who have achieved a similar or better regrowth of lucerne under long grazing duration. Cosgrove (1978) found that long grazing duration (12 day) produced higher lucerne yields than short duration (3 day), and resulted in a large number of stems ready to resume extension regrowth which produced higher post-grazing growth rate. There are several possible reasons for the superior performance of lucerne under short grazing in this trial. Lucerne shoot regrowth has a lag phase which decreases the impact of grazing on regrowth for up to 15 days

(Janson, 1978). However, the length of the lag phase is strongly influenced by crop maturity at the time of grazing - the more mature at the time of defoliation, the shorter the lag phase before resumption of fast growth (Janson, 1975). Since the grazing treatments in this trial were mostly initiated at 15-20% flowering stage of lucerne, rapid shoot growth after defoliation would have occurred due to a short lag phase. Under long duration grazing, this would have resulted in the new basal shoots being subjected to grazing and treading damage.

Short grazing duration also had between three and seven days longer regrowth periods than long duration which may have resulted in higher yields in the short term and also could have influenced the long term productivity of the pastures (refer Section 3.4.2). The cumulative effect of repeatedly less regrowth time in long grazing duration treatments may result in lower carbohydrate reserves in the plants. In addition, the plants under long duration grazing may be more dependent on root carbohydrate reserves for longer periods than in short grazing durations. Alternatively, it is possible that lucerne was subjected to more severe defoliation under long grazing. Long grazing almost always had lower residual herbage mass of around 300-400 kg $DMha^{-1}$ compared to about 500-700 kg $DMha^{-1}$ under the short grazing duration. Selective grazing of lucerne crowns in preference to less palatable pseudostems of prairie grass in particular would have resulted in a reduction of new regrowth sites and depletion of root reserves. The depletion of root reserves by grazing new crown shoots at the end of grazing under long duration (12-30 days) caused a slower rate of stem elongation, small plants with less potential growth sites (Othman, 1972), low stem density and decreased yield of lucerne (O'Connor, 1967; Leach, 1968; 1970; Peart, 1968; Lucas, 1984).

Grazing duration appears to have important implications on the quality of herbage from lucerne/grass mixtures. Short grazing resulted in higher incidence of dead material from both lucerne and grasses, and also had higher weed yields. Thus not only the quantity of edible pasture is reduced but also the quality may be decreased. The higher occurrence of dead material is in part due to the more advanced stage of maturity of the plants under short duration grazing. On the other hand, grazing animals have to feed on a low quantity as well as quality herbage for the last half of each long grazing duration, which would result in low intake and digestibility, and therefore adversely affect stock performance. Consequently short grazing may result in higher animal production provided that grazing is carried out before the plants become too mature.

Plate 6: Difference in regrowth eight days after grazing (21/3/89). Prairie grass recovering ahead of lucerne in lucerne/prairie (foreground on left) and lucerne recovering ahead of phalaris in lucerne/phalaris (background on right). The grasses are in rows parallel with the fence and lucerne is in crossing rows perpendicular to the fence.

It appears that altering grazing duration *per se* offers little scope for manipulating the composition of lucerne/grass mixtures to maintain a satisfactory balance. Other factors such as season, growth stage of plants, and species of companion grass need to be considered simultaneously. The critical factors which influence subsequent regrowth appears to be the spelling time since it influences both the maturity of the crop at grazing and the level of root carbohydrate reserves. A longer spelling period under short grazing would allow a grass dominated lucerne/grass mixture to increase lucerne production, and conversely a shorter spelling time may encourage grass production in a lucerne dominated pasture. This factor was not tested in this trial since spelling duration has always been long under both grazing durations and rotation lengths were maintained equally. Thus, the confounding effects of different regrowth periods and age of the plants at time of grazing were not examined (refer 3.4.2).

The difference in production between the two grasses was due largely to their different regrowth pattern after defoliation (Plate 6). Prairie grass grew rapidly immediately following defoliation from its dense stubble when moisture was not limiting and was always earlier recovering than lucerne. It remained without new growth for several weeks when moisture was limiting, but resumed growth immediately after rainfall or irrigation. In contrast, phalaris was very slow growing and did not respond to summer rains or irrigation and recovery was always slower than lucerne. Brown (1989) found that phalaris recovered four weeks later than prairie grass in autumn following summer drought. In addition, prairie grass was almost always in heading stage at grazing because of its faster maturity rate, while phalaris rarely reached heading stage.

Based on the results of this trial and earlier research, it can be suggested that higher production and persistence from lucerne/prairie grass mixtures could be obtained under short grazing with short spelling durations in late summmer, autumn and winter to exploit the high productivity of prairie grass during autumn, winter and spring; and long duration with long spelling periods in spring and early summer to discourage grass and encourage lucerne growth. Phalaris essentially responds in a similar manner to lucerne and consistently performed better under short grazing, although actual yields were very low compared to prairie grass. Perhaps phalaris production could be increased by using shorter spelling time so as to create a longer lag phase in lucerne thus allowing it to compete more efficiently for irradiance.

In practical farming, it may be unusual for grazing duration and/or physiology of lucerne or grass regrowth to be the guiding factors determining grazing regimes. The farmer's feed supply and demand situation usually dominates grazing decisions, and other factors such as economic viability of fencing sub-divisions, and the time and labour involved in moving stock as well as the fencing cost of sub-divisions, may well be more important considerations. Thus a grass species which is less sensitive to grazing and spelling durations, controls weed ingression and is not too competitive with lucerne, may be preferable. Phalaris appears to fulfill these roles better than prairie grass and may therefore be a better companion grass for lucerne.

3.4.2 Techniques

One of the major shortfalls of grazing duration trials is the limitation imposed by the resulting differences in spelling duration between grazings. Spelling time influences the root reserve and physiological stage of crop at the time of grazing and consequently the subsequent regrowth of lucerne. There is a dilemma between maintaining an equal number of days between grazings and the timing of the grazing treatments in order to reach an identical stage of crop maturity. For example, if both treatments were commenced at the same time, short grazing duration would be completed earlier and would, therefore, have a longer spelling time before the next grazing. Thus, it must be appreciated that under the conditions used in the present trial, the short grazing duration plots were spelled for longer periods than the long duration. Hence the differences in yields and perhaps even composition could be caused by this lack of parity. An alternative approach to design of grazing duration studies would be to have different time of grazings to maintain equal regrowth period, but this would result in the grazing duration effects being confounded by environmental conditions such as rainfall and temperature. It appears that the best method of defining the merits of a grazing management regime is to actually test its effects on animal production. For example, a grazing trial to compare farmlets of 6 paddock versus 12 paddock systems under grazing durations of 10-12 days versus 5-6 days including hay production in spring may provide more practical answers.

In this trial, the difference in number of days between the short and long grazing duration treatments were relatively small. The difference of 3 to 7 days grazing time between the treatments may not have been adequate to bring about significant differences in response especially under moisture or temperature limiting conditions. If the difference in the number

of grazing days between the short and the long duration treatments was greater such as in the study by O'Connor and Vartha (1968), perhaps the responses from the different pastures would have been different.

Despite the effort to maintain a similar residual herbage mass, long grazing almost always had lower residual herbage mass than the short grazing duration. Perhaps, this could have been better manipulated by adjusting stock numbers in the long duration plots more regularly. Alternatively short duration plots could have been grazed harder to achieve similar residual herbage mass.

CHAPTER 4

EFFECTS OF SOIL DEPTH ON LUCERNE AND LUCERNE/GRASS MIXTURES

4.1 INTRODUCTION

There is little evidence to suggest that lucerne/grass mixtures are superior to pure lucerne pastures in drought-prone areas in either shallow or deep soils. Most of the studies reporting higher annual and seasonal yields from lucerne/grass mixtures were obtained under favourable soil moisture conditions (Vartha, 1967; O'Connor, *et al.* 1968; Fraser, 1982; 1983). In those studies, lucerne/grass mixtures yielded between 16000 and 29000 kg $DMha^{-1}$ compared to a yield range of 8000 to 16000 kg $DMha^{-1}$ from pure lucerne. When rainfall is low and soil water at depth is limited, it is hypothesised that growing lucerne in association with grasses may be better than pure lucerne in exploiting the limited soil moisture from the whole soil profile. Under such conditions, the soil water storage capacity of the soil, as well as the rooting depth of the grasses may be important in determining the productivity and composition of lucerne/grass mixtures. Xu (1989) found large variations in lucerne as well as grass growth at the site of this trial and attributed it to the variation in soil depth at the site.

The soil water storage capacity is related to the depth and texture of fine material over gravel (Webb and Purves, 1983), and therefore the performance of lucerne/grass mixtures may be influenced by soil depth. Hypothetically, prairie grass will be more competitive than phalaris in shallow soils with lower stored water content at depth due to its shallow rooting characteristics. In contrast, deep rooting phalaris may be more competitive with lucerne in deep soils with higher quantities of stored water.

The aim of this experiment was to compare the performance of pure lucerne, lucerne/prairie grass and lucerne/phalaris mixtures in shallow and deep soils under dryland conditions by:

1) measuring the productivity, botanical composition, water use and water use efficiency of the three pasture types in dryland shallow and deep soils; and

2) measuring the water extraction and rooting patterns of lucerne, prairie grass and phalaris in pure stands and in mixed stands of lucerne with prairie grass or phalaris.

4.2 MATERIALS AND METHODS

4.2.1 Experimental design

This experiment was conducted on the same site as the grazing duration experiment (Chapter 3). Soil depth to gravel was determined using a motorised corer and this information was used to plot the map showing the variation in soil depth (Figure 4.1). This soil depth map related closely to the variation in vegetation shown by the aerial photograph taken of the site in February 1988 (Plate 7). To study the effects of soil depth, mini-plots of 8 m^2 area were demarcated within the 0.042 ha main plots of the grazing experiment as shown in Figure 4.1. Table 4.1. shows the different treatment combinations and number of mini plots used in this study.

Table 4.1 Treatments of the lucerne/grass mixture soil depth trial

Pasture	Soil depth*	No.of mini-plots
Lucerne	shallow	8
	deep	8
Lucerne/prairie	shallow	4
	deep	4
Lucerne/phalaris	shallow	8
	deep	8

*Shallow = <50 cm fine soil profile depth

Deep = >80 cm fine soil profile depth

For pure lucerne and lucerne/phalaris pastures 8 mini-plots (4 shallow and 4 deep) were located on plots under each short and long grazing duration treatments. In the case of

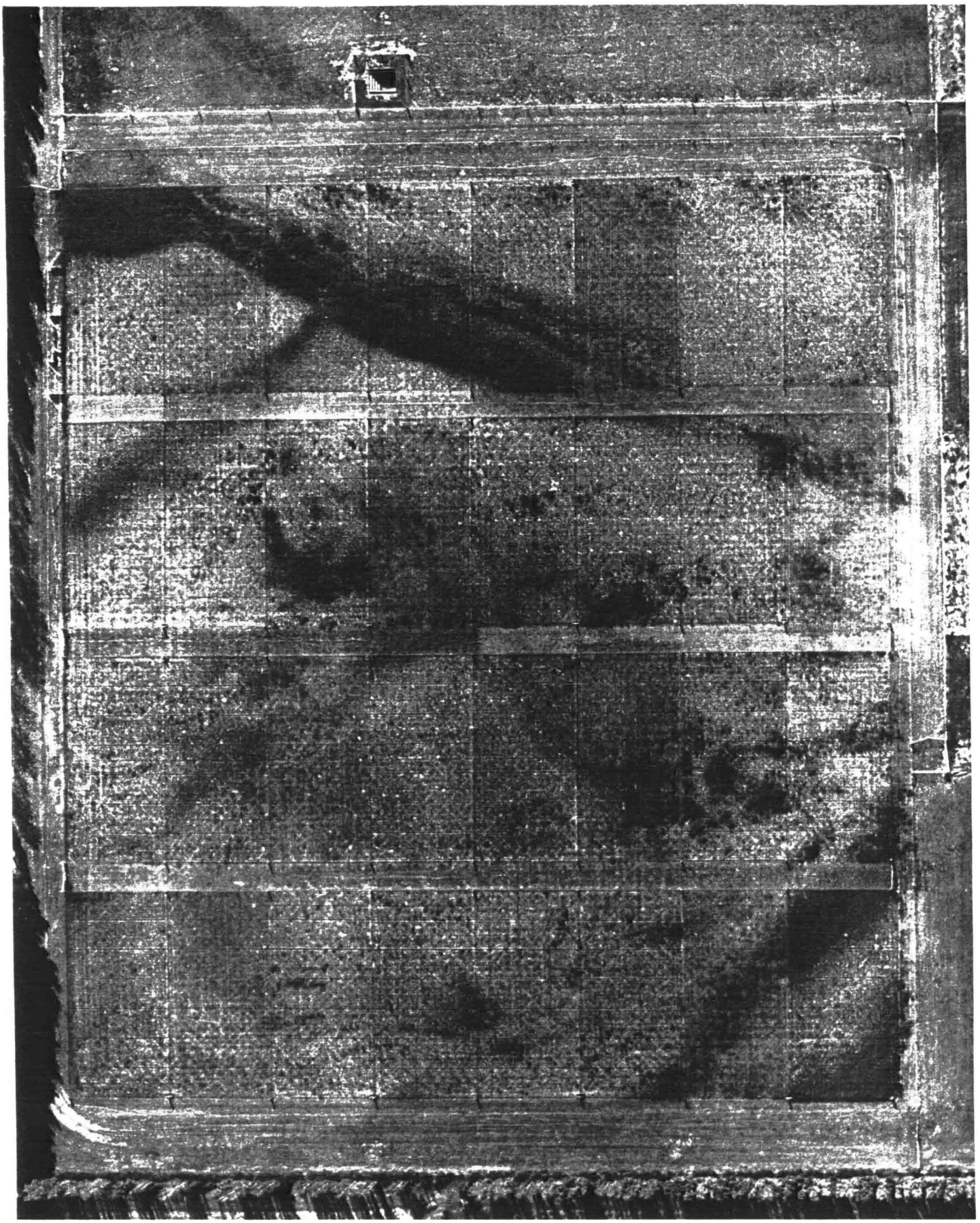


Plate 7: An aerial view of the trial site (16/2/88). The dark bands represent deep soils.

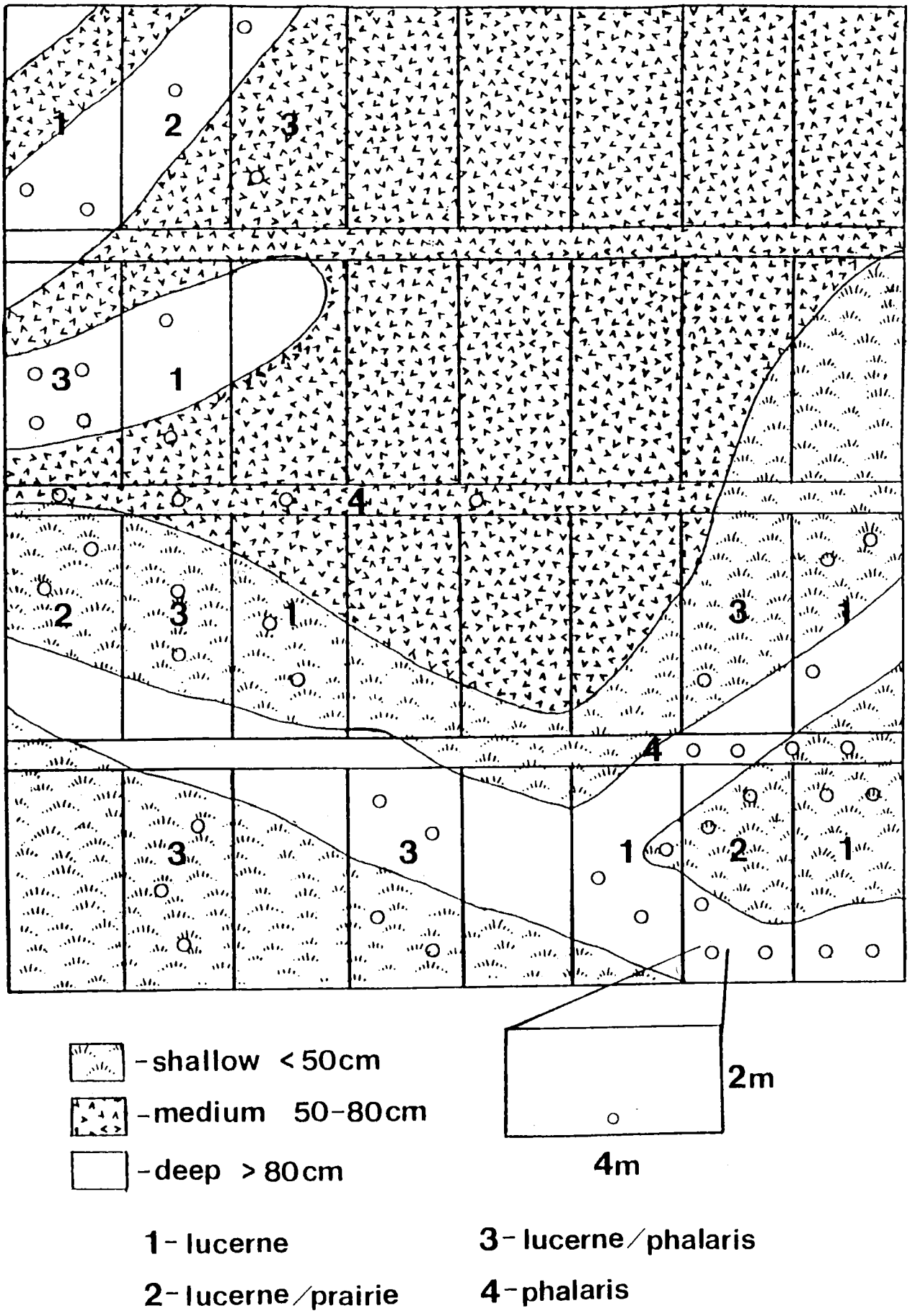
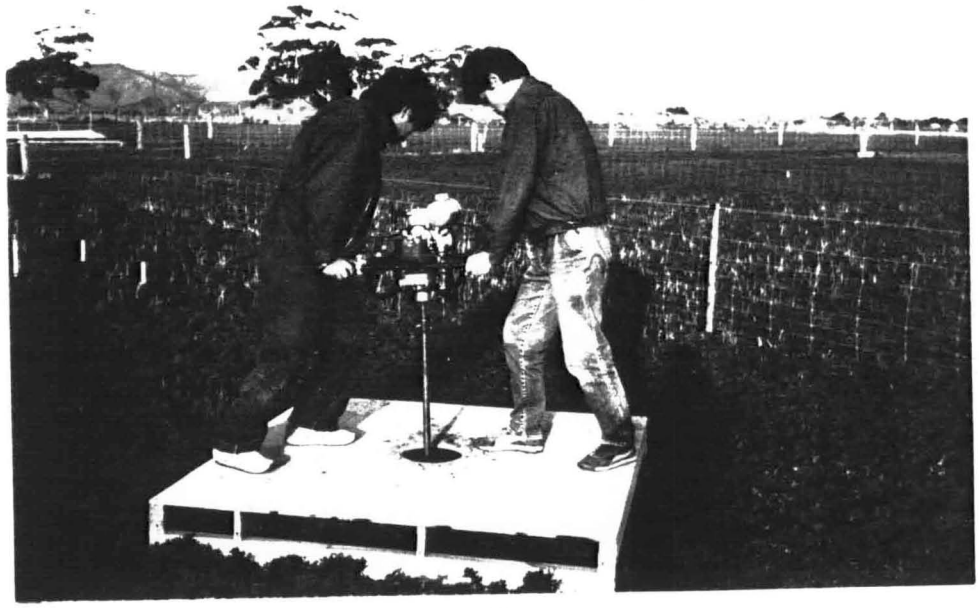


Figure 4.1 Soil map and sample plot locations.



a

b

Plate 8: a) Drilling access holes for neutron measurement tubes using a motorised auger; the wooden platform was used to protect pastures from trampling.

b) The Troxler Neutron Moisture Meter in use on a mini-plot. In the background is another 4 m x 2 m mini-plot.

lucerne/prairie grass only 4 plots for each depth under long grazing duration treatment could be located due to lack of deep soil area of this pasture under short grazing. An additional 8 mini-plots were located on the white clover/phalaris mixture on the raceways which have become nearly pure phalaris pastures (4 each in deep and shallow soil). While locating the mini-plot, care was taken to avoid urine patches, stock camps and also to obtain a balanced proportion of lucerne and grass plants.

4.2.2 Herbage sampling

Before the January 1988 grazing, four 0.1 m^2 quadrats were cut from each sub-plot as there was very little material. In other harvests two quadrats were cut following a predetermined protocol to avoid sampling from the same spots at subsequent harvests. Dry matter yields and botanical composition were determined using the standard technique outlined by Boswell (1982).

4.2.3 Soil water measurements

Aluminium access tubes for the neutron probe were installed in each plot between July and August 1988 using a motorised corer (Plate 8a) to drill the access holes. The first measurements were taken approximately one month after installing the tubes in order to allow time for the surrounding soils to stabilise. Soil water content was measured using a Troxler Neutron Moisture Meter (NMM), model 3300, (Plate 8b) for that part of the profile more than 20 m below the soil surface, and by gravimetric determination for the top 20 cm of the profile. Soil water content was measured at approximately fortnightly intervals (1988-29/9, 13/10, 22/10, 29/10, 8/11, 21/11, 29/11, 8/12, 19/12; 1989-6/1, 19/1, 1/2, 1/3, 18/3, 31/3, 14/4 and 26/4) for the calculation of water use and water use efficiency over each grazing cycle during the experimental period. With the NMM, readings of 4 minute standard counts were taken in the shield before each set of measurements in the field and in water after each set of measurements. Count readings were made for 30 seconds at every 10 cm interval from 20 cm below ground surface to the bottom of the tube.

The NMM was calibrated using the calibration equation derived by McKenzie (1987) for the soil at the same site. The equation was:

$$VWC\ (mm) = -0.0495 + 0.61\ CR \qquad (1)$$

where VWC = volumetric water content; CR = count ratio read from the Neutron Moisture Meter. This was similar to the calibration equation derived by Sherrel (1987), who previously worked on an adjacent site studying water use by lentils. (See Appendix 3 for further details).

Gravimetric determination of soil water content was made by taking a soil core of 98 cm^3 volume, to a depth of 20 cm. One core was taken per plot at each reading within a distance of 30 cm from the tubes.

4.2.4 Calculation of water use

Water use was assumed to be equivalent to evapotranspiration (ET) between the grazing periods. It was estimated by subtracting the total soil water content of successive measurements from the preceding ones until the last measurement before sampling. This was then subtracted from the sum of rainfall and irrigation received during the period. The resultant is the amount of water removed from the profile either through evapotranspiration (ET) or drainage (D). Water loss through drainage at the site was assumed to be nil and hence the equation used was:

$$ET = DSWC - (I + R) \qquad (2)$$

where ET = water use; DSWC = change in soil water content;
I = irrigation; R= rainfall.

4.2.5 Calculation of water use efficiency

The water use efficiency (WUE) of dry matter production was calculated as the maximum amount of above ground dry matter harvested with a residual of 300 kg $DMha^{-1}$ divided by the quantity of water used in producing it:

$$WUE = DM\ yield / ET \qquad (3)$$

In all cases, maximum dry matter was taken as the amount of dry matter present before the start of grazing.

4.2.6 Water extraction pattern

The neutron measurements for the first cycle from post grazing to pre-grazing covering the period 20th September to 11th November 1988 were used to determine the depth and pattern of water extraction by the different pastures. This period went through a drying cycle uninterrupted by either rainfall or irrigation and consisted of five measurements (29/9, 13/10, 22/10, 29/10, 7/11/88). Four tubes for each pasture type and soil depth combination were selected based on the similarity in initial soil water content. The pure phalaris plots were included in this analysis. The water content at each depth was tested for significant changes from the previous measurement. The NMM volumetric water contents listed are all per 10 cm layer of soil. The depth at which no decrease in water content over time was observed was assumed to be the maximum depth from which water was extracted.

4.2.7 Root sampling technique

A motor driven auger developed by the Soil Science Department of Lincoln University, was used to extract soil cores. This machine has a boring depth of 1 m and an inside core diameter of 5 cm. The machine required two operators and took 15 to 20 minutes to extract a 80 cm deep sample. Three samples were taken from each plot of the lucerne/grass mixtures within 5 m of the neutron access tubes between 8 and 14 May 1989. The first core was taken by placing the core on top of a lucerne plant, the second on top of a grass, and the third from between the crossing rows of the two species. From the pure lucerne and grass pastures only two cores were taken: one from the row on top of a plant and the other from between the rows. The root cores were taken only from the plots with deep soil profile. To facilitate comparisons, core samples were also taken from mixtures of lucerne/ryegrass and white clover/ryegrass and pure prairie grass and phalaris. The lucerne/ryegrass sample was taken from a pure lucerne plot which was subsequently invaded by volunteer ryegrass plants while the other samples were taken from plots located on the raceway.

The soil cores were transported intact in plastic transport tubes to the root laboratory where they were cut into one 20 cm length sub-section (from top of the core) and six 10 cm length sub-sections (below 20 cm). These subsections were placed in labelled round sieves

with 0.2 mm mesh size and partially immersed in buckets of water. Using a fine spray of water, the samples were gently stirred and manipulated to separate the roots from the soil. The cleaned roots were collected with tweezers and transferred to separate containers of clean water to allow further cleaning through sedimentation of soil particles. Grass and lucerne roots were identified visually. A total of 26 cores, each having 7 sub-sections were processed with each core sample taking about an hour to wash and clean. The cleaned roots were then oven dried for 48 hours in a hot air oven at 75^0C and weighed using a highly sensitive electric balance (Mettler AE200; Victor Watson Ltd, NZ).

4.2.8 Statistical analysis and data presentation

It was revealed that the grazing duration treatment had no effect on the yields and water use of pure lucerne and lucerne/phalaris when analysed as a 2 x 2 x 2 factorial design with two pasture types (pure lucerne and lucerne/phalaris); two grazing durations (long and short); and two soil depth (shallow and deep). Hence the long and short grazing duration treatments on these two pastures were pooled together to obtain 8 replicates each for shallow and deep soils. The prairie grass plots under the long duration grazing treatments and consisting of 4 replications for each soil depth were included to analyse the data as an unbalanced design using SAS GLM procedure. A typical output is shown in Appendix 4.

4.3 RESULTS

4.3.1 Total dry matter yield

The total yield of pure lucerne at 12700 kg $DMha^{-1}$ was significantly higher than lucerne/prairie grass at 10400 kg $DMha^{-1}$, but was not statistically different from the 11600 kg $DMha^{-1}$ of lucerne/ phalaris mixture (Table 4.2). Deep soils produced a significantly higher yield of 12600 kg $DMha^{-1}$ than shallow soils at 10900 kg $DMha^{-1}$. The total yields of pure lucerne and lucerne/phalaris were not affected by soil depth, but lucerne/prairie grass produced only 8500 kg $DMha^{-1}$ on shallow soils compared to 12300 kg $DMha^{-1}$ on deep soils (Figure 4.2).

The pure lucerne pasture was consistently higher yielding than lucerne/prairie grass but the difference was significant ($P<0.05$) only at the March 1989 harvest. Similarly, pure lucerne was higher yielding than lucerne/phalaris only at the November 1988 harvest.

Although the lucerne/phalaris was marginally higher yielding than the lucerne/prairie grass at all the harvests other than November 1988, the difference was not significant. At the November 1988, January 1989 and March 89 harvests, deep soils produced 580, 710 and 700 kg DMha^{-1} respectively more than shallow soils, but at the September 1989 harvest, shallow soils out-yielded deep soils by 680 kg DMha^{-1}.

There was a significant interaction ($P<0.05$) between pasture type and soil depth on the dry matter yields of September 1989 harvest (Figure 4.3). The dry matter yield of lucerne/phalaris on the shallow soils was higher (3200 kg DMha^{-1}) than on deep soils (2800 kg DMha^{-1}), whereas pure lucerne and lucerne/prairie grass yields were similar on both shallow and deep soils.

Table 4.2 The effect of pasture type and soil profile depth on total yields at different grazing dates (kg DMha^{-1}).

	GRAZING DATE					
	Nov'88	Jan'89	Mar'89	May'89	Sep'89	Total
Pasture type						
Lucerne	2420	1900	3220	2110	3070	12700
Lucerne/prairie	2040	1430	2250	1740	2930	10400
Lucerne/phalaris	1840	1690	2960	1780	3290	11600
LSD (P=0.05)						
1-2; 2-3	483	504	907	446	435	1600
1-3	394	411	740	364	355	1300
Soil Profile Depth						
Shallow	1820	1370	2570	1900	3290	10900
Deep	2400	2080	3270	1920	2970	12600
LSD (P=0.05)	352	368	662	326	318	1200
Interactions (P)	0.29	0.21	0.63	0.13	0.02	0.07
CV%	24	33	35	26	15	15

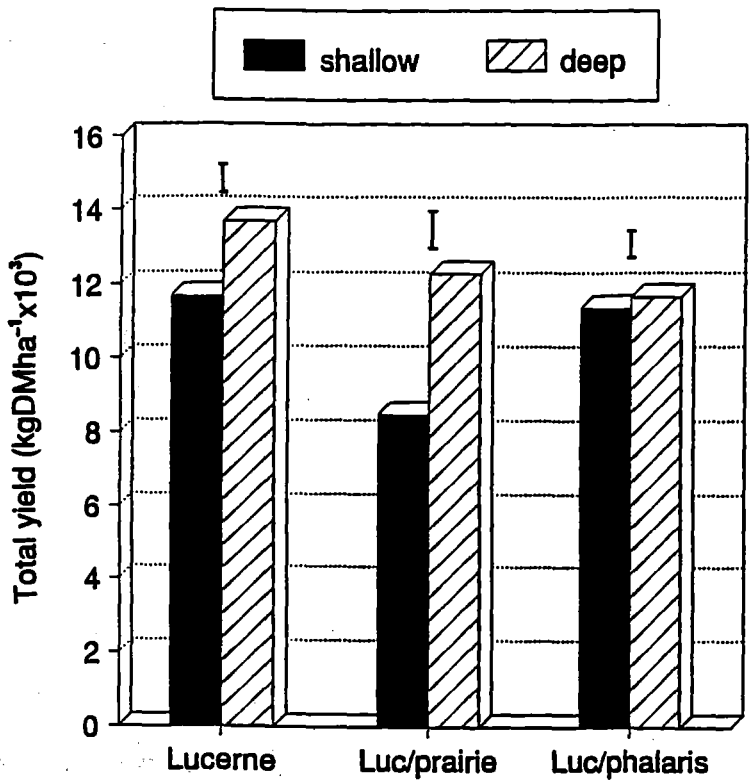


Figure 4.2 Interaction (P=0.07) between pasture type and soil depth on the total dry matter yields of all harvests (I = S.E.M.).

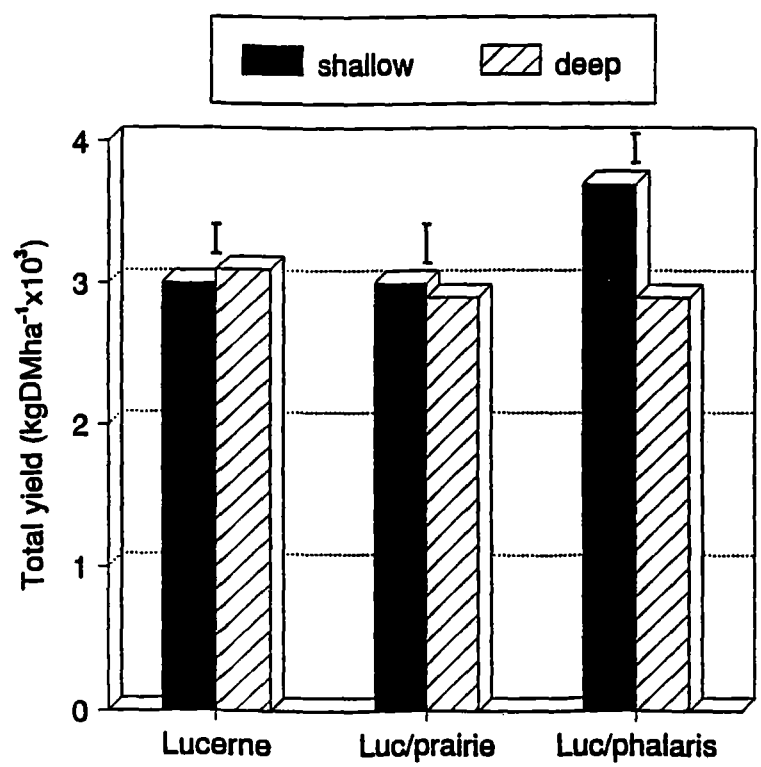


Figure 4.3 Interaction (P=0.02) between pasture type and soil depth on the total dry matter yields of September 1989 (I = S.E.M.).

4.3.2 Lucerne dry matter yield

The total lucerne yield of 12300 kg $DMha^{-1}$ from the pure lucerne pasture was significantly higher than the lucerne yield of the lucerne/phalaris, and nearly twice that of the lucerne/prairie grass at 6500 kg $DMha^{-1}$ (Table 4.3). Lucerne production on deep soils at 11100 kg $DMha^{-1}$ was 1800 kg $DMha^{-1}$ more than on shallow soils. The total lucerne yields of pure lucerne and lucerne/phalaris were not affected by soil depth, but the lucerne yield of lucerne/prairie grass was severely reduced in shallow soils from 8500 kg $DMha^{-1}$ to 4000 kg $DMha^{-1}$ (Figure 4.4)

At all harvests, there was significantly more lucerne in pure lucerne plots than in lucerne/prairie grass plots. However, only at the November 1988 and May 1989 harvests, did pure lucerne produce more lucerne than the lucerne/phalaris (Table 4.3). Lucerne yield of the lucerne/phalaris was significantly higher than that of the lucerne/prairie grass in the March, May and September 1989 harvests by 62%, 70% and 65% respectively.

Table 4.3 The effects of pasture types and soil profile depth on lucerne yields at different grazing dates (kg $DMha^{-1}$).

	GRAZING DATE					
	Nov'88	Jan'89	Mar'89	May'89	Sep'89	Total
Pasture type						
Lucerne	2420	1900	3220	2110	2680	12300
Lucerne/prairie	1090	1190	1690	840	1720	6500
Lucerne/phalaris	1480	1640	2750	1520	2514	9900
LSD (P=0.05)						
1-2; 2-3	463	495	762	382	513	1650
1,3	378	404	663	312	419	1350
Soil Profile Depth						
Shallow	1500	1290	2380	1570	2500	9300
Deep	2050	2020	3070	1660	2340	11100
LSD (P=0.05	338	361	593	279	375	1206
Interactions (P)	0.55	0.15	0.61	0.01	0.01	0.02
CV%	29	33	33	26	24	18

Lucerne production was higher on the deep soils at all harvests except at May 1989 and September 89, when the differences were not significant. There were significant interactions between pasture type and soil depth on the May 1989 and September 1989 lucerne yields (Figure 4.5). In May 1989, lucerne production between pure lucerne and lucerne/phalaris was not affected by soil depth, but lucerne production in lucerne/prairie grass was only 300 kg $DMha^{-1}$ in the shallow soil compared to 1200 kg $DMha^{-1}$ in the deep soil. In September 1989, lucerne with prairie grass was again more productive in the deep soil while lucerne with phalaris gave higher yields on the shallow soils.

There were consistently significant differences in the proportion of lucerne in the lucerne/prairie grass between deep and shallow soils, whereas lucerne percentage in the lucerne/phalaris was similar in both soils at all the harvests (Figure 4.6). Maximum lucerne proportions in the lucerne/prairie grass on shallow and deep soils respectively were 60% and 82% in January 1989, and minimum proportions were 5% and 60% in May 1989. The lucerne contribution to total yield of lucerne/phalaris increased to a mean maximum of 95% in January 1989 and gradually declined to a minimum of 75% in September 1989. On both soils, there was an increase in the lucerne content of the lucerne/prairie grass and a decrease in lucerne content of lucerne/phalaris in September 1989. On the deep soils there were no significant differences in the percentage of lucerne between the two mixtures, but on the shallow soils lucerne content in the lucerne/phalaris was significantly higher than the lucerne/prairie grass at all harvests.

4.3.3 Grass dry matter yields

The total grass yields from lucerne/prairie grass and lucerne/phalaris were 3900 and 1500 kg $DMha^{-1}$ respectively (Table 4.4). Prairie grass yields with a range of 240 kg $DMha^{-1}$ in January 1989 to 1200 kg $DMha^{-1}$ in September 1989 were significantly higher than phalaris which gave a much lower yield range of 50 kg $DMha^{-1}$ in January 1989 to 700 kg $DMha^{-1}$ in September 1989.

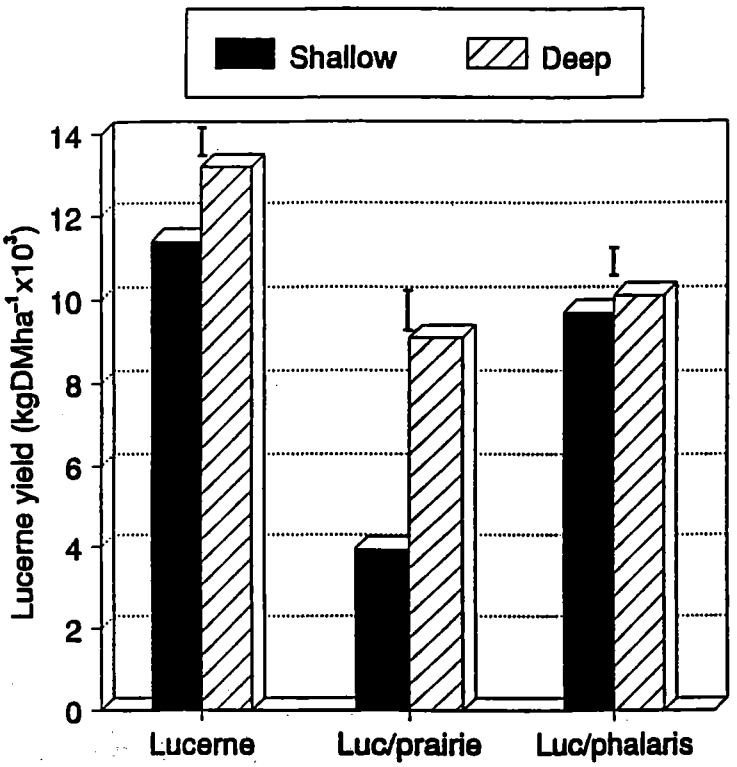


Figure 4.4 Interaction (P=0.02) between pasture type and soil depth on the total lucerne dry matter yields of all harvests (I = S.E.M.)

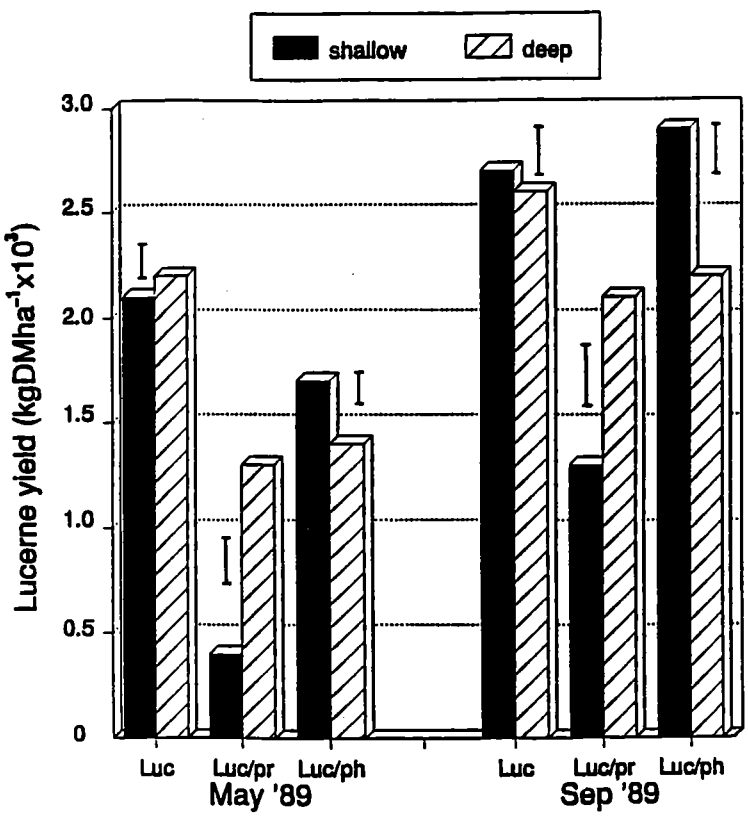


Figure 4.5 Interactions between pasture type and soil depth on the lucerne dry matter yields of May 1989 (P=0.01) and September 1989 (P=0.02) (I = S.E.M.)

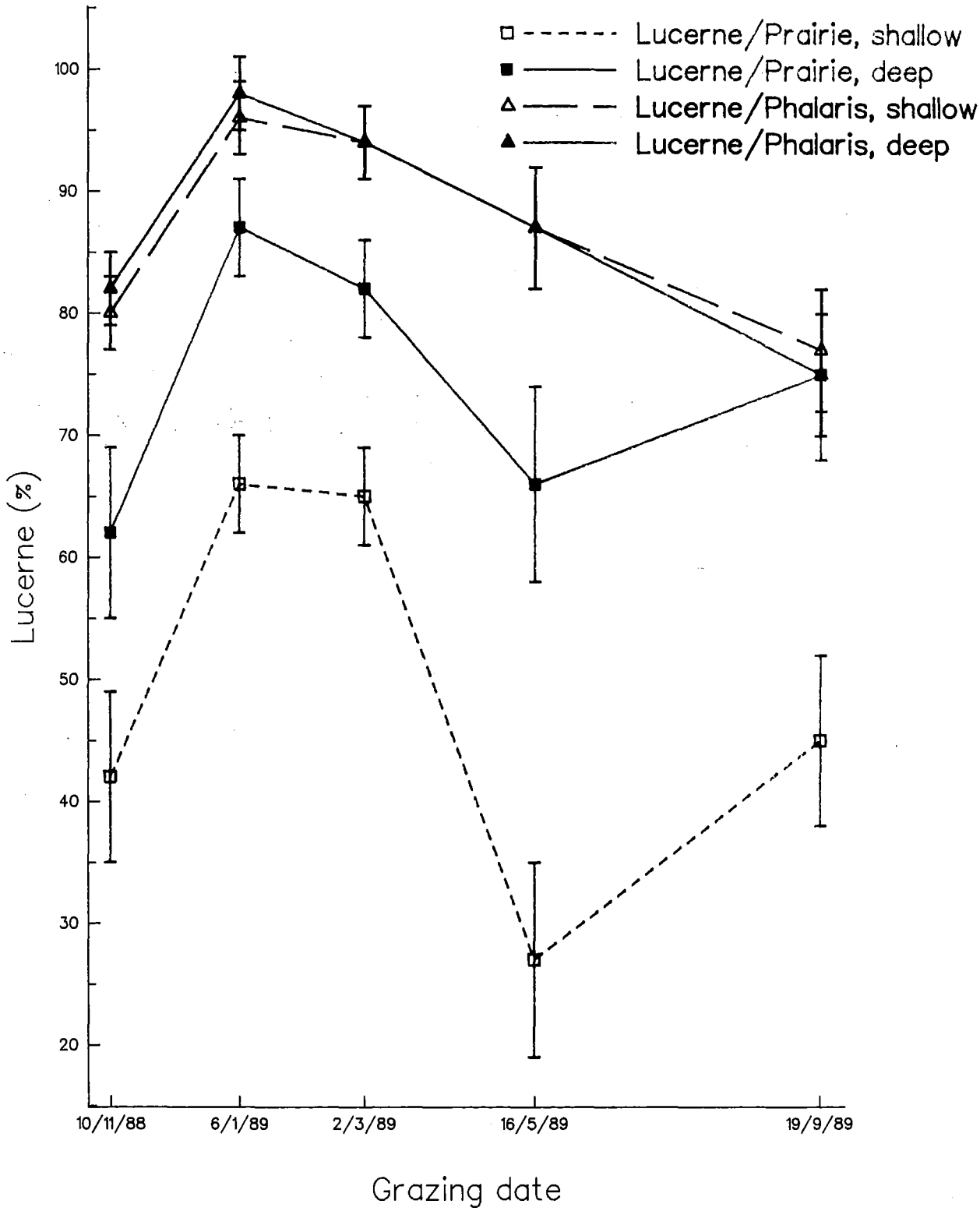


Figure 4.6 Lucerne dry matter yield as a percentage of total dry matter yields of lucerne/grass mixtures in shallow and deep soils at different grazing dates (Bars=S.E.M.).

Table 4.4 The effects of pasture types and soil profile depth on grass yields at different grazing dates (kg $DMha^{-1}$).

	GRAZING DATE					
	Nov'88	Jan'89	Mar'89	May'89	Sep'89	Total
Pasture type						
Lucerne/prairie	950	240	560	930	1190	3900
Lucerne/phalaris	360	50	190	190	700	1500
LSD (P=0.05)	311	96	248	328	404	800
Soil Profile Depth						
Shallow	546	130	280	540	1090	2600
Deep	573	100	330	340	640	2000
LSD (P=0.05)	293	91	234	309	381	700
Interactions (P)	0.84	0.40	0.94	0.53	0.06	0.15
CV%	61	92	89	83	51	36

Soil depth had no effect on grass production except in the September 1989 harvest when shallow soils produced 1090 kg $DMha^{-1}$, nearly 40% more than the production from deep soils of 640 kg $DMha^{-1}$. The interaction between pasture type and soil depth was nearly significant (P=0.06) on the grass yields of September 1989 (Figure 4.7). Prairie grass gave 1700 kg $DMha^{-1}$ on the shallow soils compared to only 800 kg $DMha^{-1}$ on the deep soils. In contrast phalaris gave similar yields of 700 and 650 kg $DMha^{-1}$ on shallow and deep soils respectively.

Both grasses made their highest contributions to total yields in September 1989 (Appendix 5). Prairie grass proportions in total yield of lucerne/prairie grass ranged from 35% in January to 70% in March 1989 on shallow soils and from 15% in January 1989 to 38% in November 1988 on deep soils. In contrast phalaris made little contribution to total yields (<15%) in either soil types at all other harvests except in November 1988 and September 1989, when it provided around 20% of the total yield.

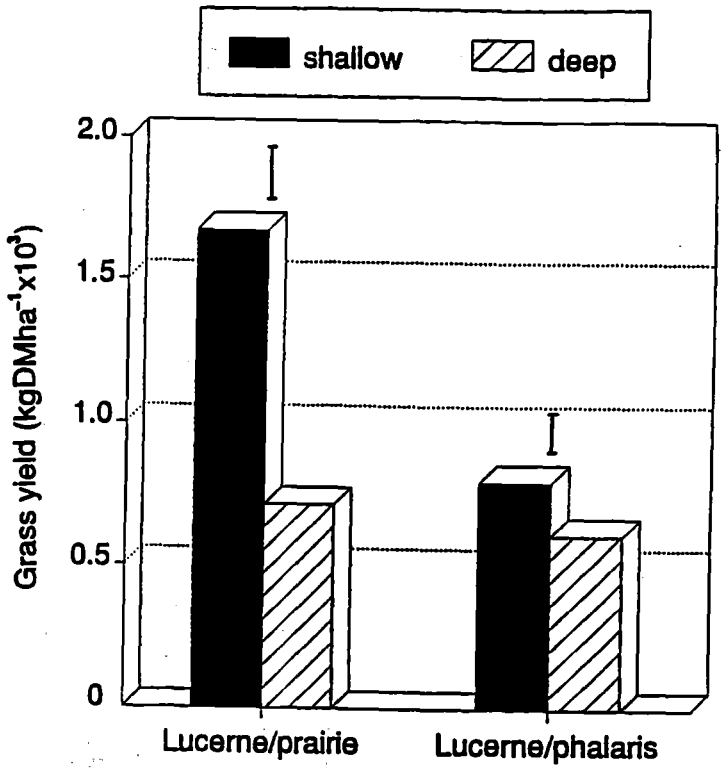


Figure 4.7 Interaction (P=0.06) between pasture type and soil depth on the grass dry matter yields of Sep 1989 (I = S.E.M.).

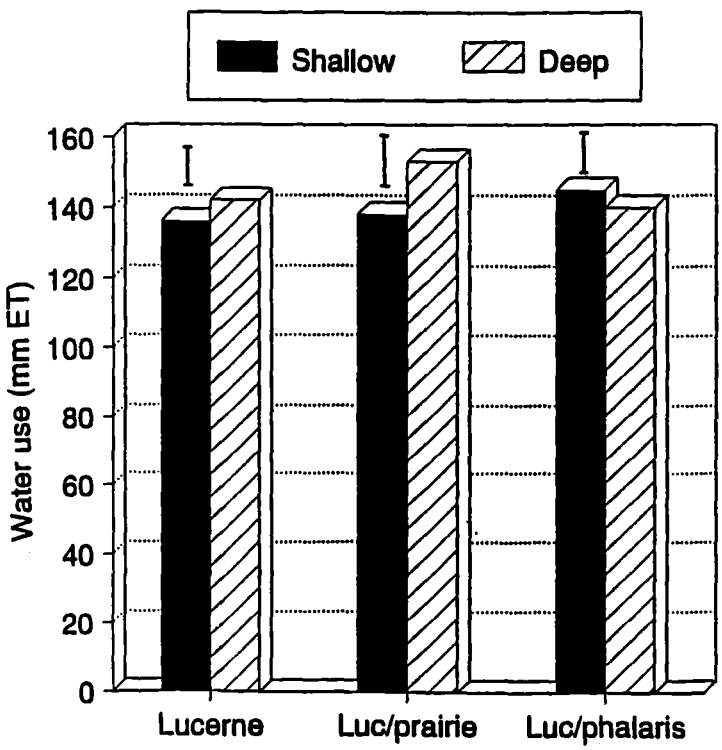


Figure 4.8 Interaction (P=0.06) between pasture type and soil depth on the water use (ET) of March 1989 (I = S.E.M.).

4.3.4 Weed dry matter yield

Pure lucerne produced 390 kg $DMha^{-1}$ of weed in September 1989, which was significantly higher than the weed yields from lucerne/prairie grass (10kg $DMha^{-1}$) and lucerne/phalaris (100kg $DMha^{-1}$) (Appendix 6). Weed yield was also higher in the deep soils than the shallow soils. Pure lucerne produced 280 kg $DMha^{-1}$ in the shallow soils and 500 kg $DMha^{-1}$ in the deep soils.

4.3.5 Water use

The total water use (ET) over the whole period was 384 mm from lucerne, 376 mm from lucerne/prairie grass and 375 mm from lucerne/phalaris (Table 4.5).

Table 4.5 The effects of pasture types and soil profile depth on the water use (ET) at different sampling periods (mm).

	SAMPLING PERIOD				
	1988		1989		
	29/9-8/11	9/11-6/1	7/1-1/3	3/3-16/5	Total
Pasture type					
Lucerne	80	79	141	85	384
Lucerne/prairie	72	82	141	77	376
Lucerne/phalaris	72	81	142	79	375
LSD (P=0.05)					
1-2; 2-3	13	12	10	10	25
1-3	10	10	8	8	20
Soil Profile Depth					
Shallow	63	73	140	84	360
Deep	88	88	144	78	398
LSD (P=0.05)	9	9	7	8	18
Interactions (P)	0.64	0.51	0.06	0.37	0.61
CV%	19	17	7	14	7

Deep soil ET at 398 mm was significantly higher than the shallow soil ET of 360 mm. During the spring (29/9-8/11/88) and early summer (9/11/88-6/1/89), ET was higher in the deep soils by 21% and 30% respectively. When soil moisture was not limiting in autumn (3/3-16/5/89), ET was 10% higher on the shallow soils. There was a marginally significant interaction (P=0.06) between the pasture type and the soil depth on the ET of the late summer period (7/1-2/3/89). Pure lucerne and lucerne/prairie grass ET was higher on deep soils but lucerne/phalaris ET was similar on both soils (Figure 4.8).

4.3.6 Seasonal water use efficiency

The mean water use efficiency (WUE) of pure lucerne of 25 kg DMha^{-1}mm^{-1}H$_2$O was significantly higher than the mean WUE of both the lucerne/prairie grass (20 kg DMha^{-1}mm^{-1}H$_2$O) and the lucerne/phalaris (22 kg DMha^{-1}mm^{-1}H$_2$O) mixtures (Table 4.6).

Table 4.6 The effects of pasture types and soil profile depth on the seasonal water use efficiency (WUE) (kg DMha^{-1}mm^{-1}H$_2$O).

	SAMPLING PERIOD				
	1988		1989		
	29/9-8/11	9/11-6/1	7/1-1/3	3/3-16/5	Mean
Pasture type					
Lucerne	30	24	23	25	25
Lucerne/prairie	28	16	15	24	20
Lucerne/phalaris	26	21	21	22	22
LSD (P=0.05)					
1-2; 2-3	4.4	5.5	6.50	5.5	3.8
1-3	3.6	4.5	5.3	4.5	3.1
Soil Profile Depth					
Shallow 29	19	19	23	21	
Deep	27	24	23	25	24
LSD (P=0.05)	3	4	5	4	3
Interactions (P)	0.10	0.27	0.76	0.10	0.21
CV%	19	29	36	26	19

The seasonal WUE values of the lucerne/prairie grass were significantly lower than the pure lucerne and the lucerne/phalaris during the summer periods (9/11/88-6/1/89 and 7/1-2/3/89) and similar during the spring (29/9-8/11/88)and autumn (3/3-16/5/89) seasons. In contrast the seasonal WUE of the lucerne/phalaris was significantly lower than pure lucerne only in spring 1988, but at all other seasons it was comparable to lucerne alone.

The WUE of the pastures were generally higher in the deep soils than shallow soils but in the spring and winter seasons, there were no differences. Over the whole period mean WUE of the pastures in the shallow soils was 21 kg $DMha^{-1}mm\text{-}^{1}H_2O$, which was significantly lower than in the deep soils with a mean WUE of 24 kg $DMha^{-1}mm^{-1}H_2O$.

4.3.7 Water extraction pattern

The initial water content at all depths was similar under all of the pastures. Moisture contents of both shallow and deep soils were highest at the top 20 cm depth containing 40-45 mm of water. At 30 cm and 40 cm depth in the shallow soils, water content was similar at an average of 15-20 mm (Figure 4.9). In the deep soils, all three pastures had similar water contents of approximately 15 mm between 30 and 60 cm but below 70 cm water pure lucerne had higher water contents (10-15 mm) than either mixtures (10 mm) (Figure 4.10).

In the shallow soils, all the three pasture types extracted significant amounts of water between the first (29/9/88) and the second (8/10/88) measurements at all of the depths measured (Figure 4.9). Water content was reduced by 15 mm at 20 cm depth by lucerne, phalaris and lucerne/phalaris and by 20 mm under lucerne/prairie grass mixture. At the 30 cm and 40 cm depth, pure lucerne and lucerne/prairie grass extracted more water than pure phalaris and
lucerne/phalaris. Between the second and third (22/10/88) measurement dates, when water content reached approximately 20 and 12 mm respectively at the 20 and 30 cm depth, only pure lucerne and pure phalaris were able to make significant extractions.

In the deep soils, pure lucerne extracted significant quantities of water up to the sampling depth of 1 m between the first and the second measurements after which there were no further significant changes in soil water content at all depths (Figure 4.10). Pure phalaris extracted significant quantities of water to a depth of 50 cm between the first and second measurements and to the 20 cm depth between second and third measurements. The soil water

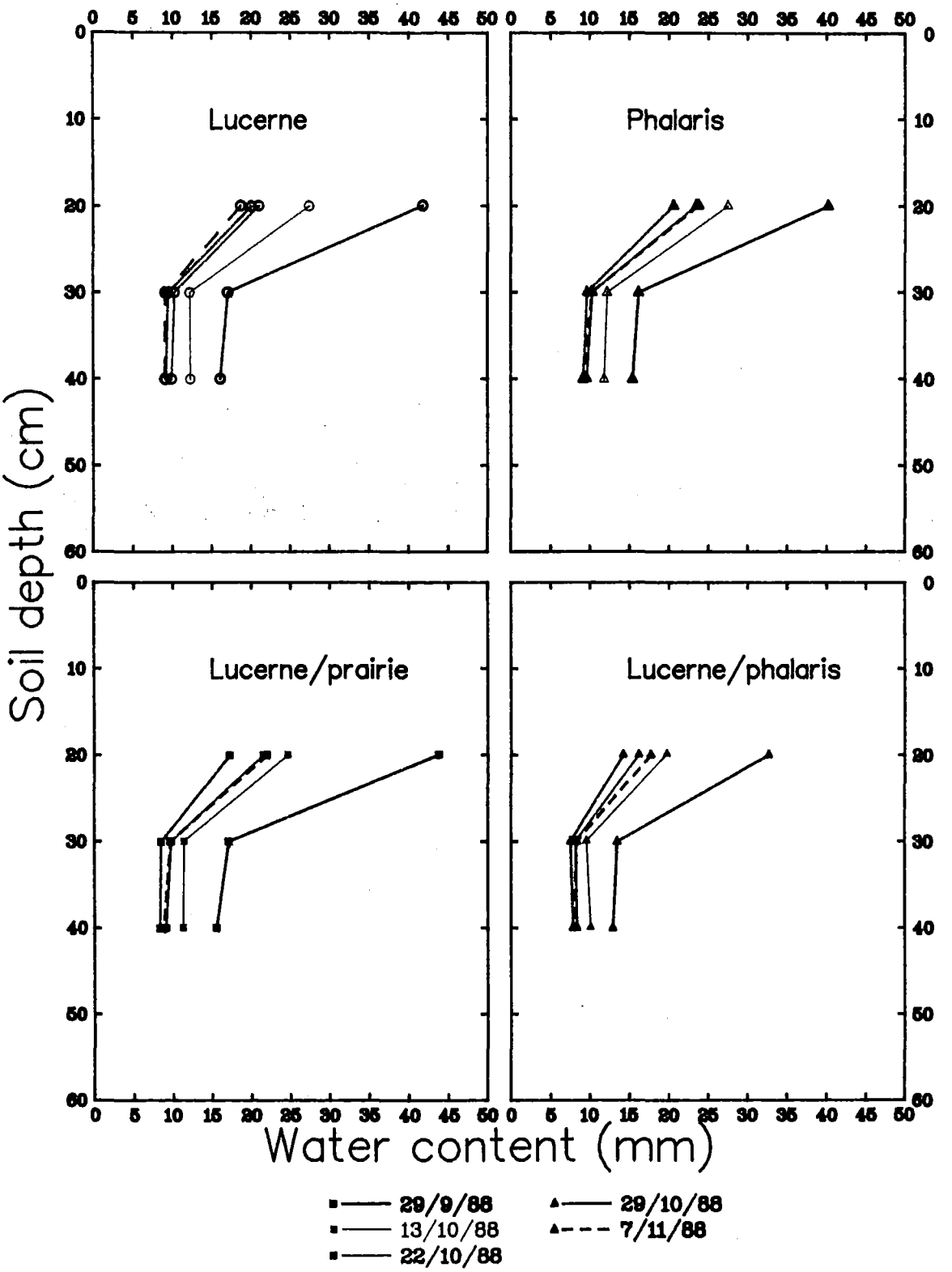


Figure 4.10. Changes in soil water content under different pastures in the shallow soils during a drying cycle in spring, 1988. (Horizontal bars = S.E.M. >1.0).

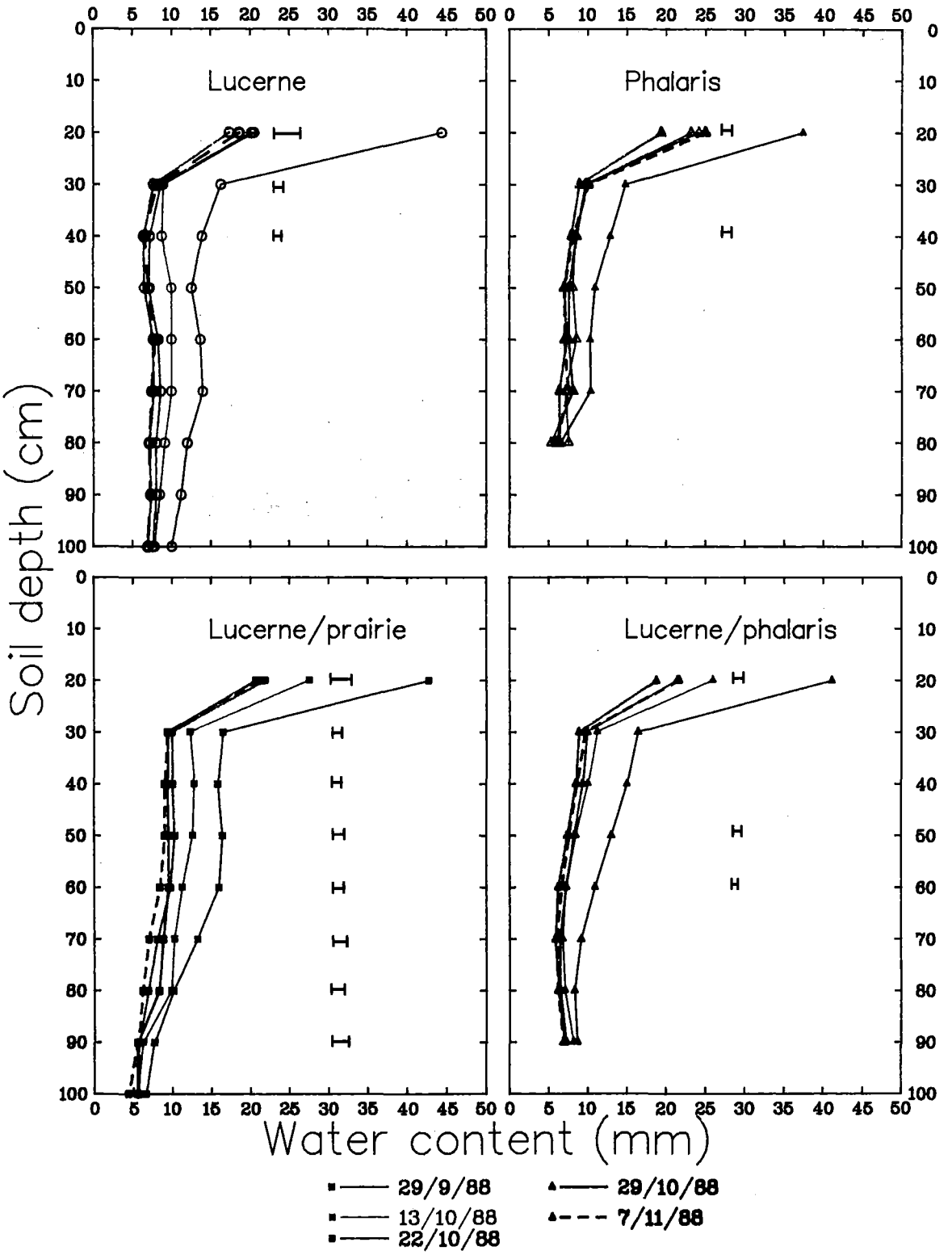


Figure 4.10. Changes in soil water content under different pastures in the deep soils during a drying cycle in spring, 1988. (Horizontal bars = S.E.M. where more than 1.0 mm)

contents under lucerne/prairie grass and lucerne/phalaris were significantly different up to the 80 cm depth between the first and the second measurements. Between the second and third measurements, changes in soil water content under lucerne/prairie grass occurred up to the 40 cm depth whereas under lucerne/phalaris it was significant only at the 20 cm depth. The soil water contents at which stages no further extraction occurred were 20 mm at the 0-20 cm depth and 10 mm below the 30 cm depth in both shallow and deep soils, which applied uniformly for all the different pastures.

4.3.8 Root yields and distribution

Figure 4.11. shows the root density of the different species observed in pure stands. Prairie grass root yield in the top 20 cm of the soil profile (6 $kgDMm^{-3}$) was higher than that of phalaris (4 $kgDMm^{-3}$). At depths below 20 cm, phalaris had higher root yields than prairie grass. Roots of lucerne as well as both the grasses were observed down to 70 cm depth. Both prairie grass and phalaris gave higher root yields than ryegrass which had roots only in the top 30 cm. Lucerne had 73 % of its roots in the top 20 cm (12 $kgDMm^{-3}$), prairie grass 84%, phalaris 60% and ryegrass 94%. (Refer Appendix 7 for further details).

The root density of the lucerne/phalaris in the top 20 cm of the soil was 10 $kgDMm^{-3}$ compared to 6 $kgDMm^{-3}$ of the lucerne/prairie grass (Figure 4.12). Lucerne/phalaris had a considerable amount of root up to 80 cm depth with a significant contribution from phalaris till 70 cm depth. In the lucerne/prairie grass however, root yields below 50 cm were negligible and no prairie grass roots were observed below this depth. Lucerne/prairie grass had 70% of the total roots in the top 20 cm, which consisted of 60% lucerne and 40% grass roots. In contrast lucerne/phalaris had only 54% of its total root in the top 20 cm, of which 88% was lucerne roots. Root yields of the lucerne/perennial ryegrass mixture revealed that the invading ryegrass plants had no apparent effect on the root yields of lucerne, with lucerne contributing to 82% of the total root yield in the top 20 cm. In a white clover/ryegrass stand, white clover roots were observed only in the top 20 cm, whilst ryegrass roots were traced down to a depth of 40 cm. (Also refer Appendix 8 for details).

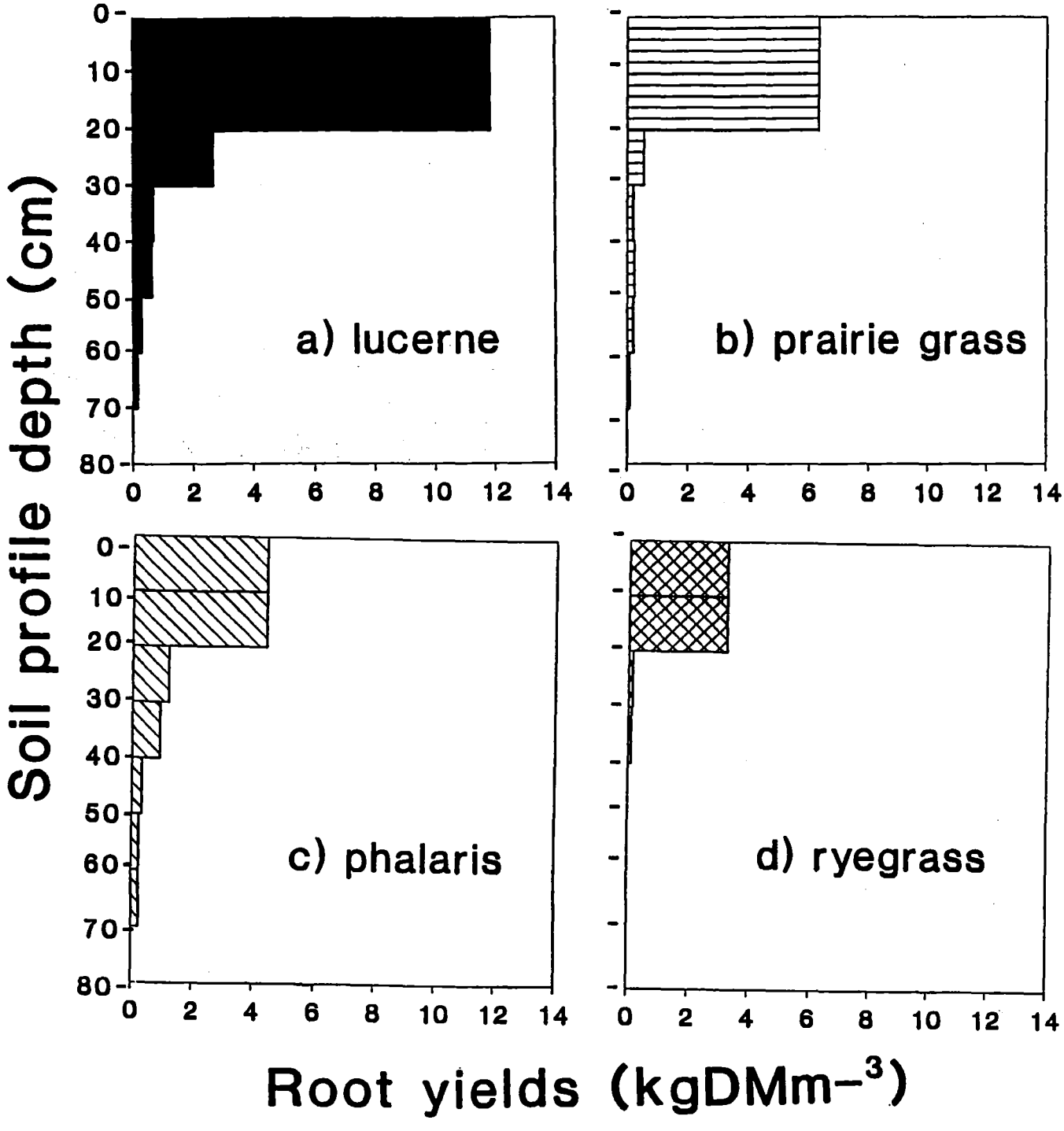


Figure 4.11 Root dry matter yields of pure pastures of lucerne, prairie grass, phalaris and perennial ryegrass at different depths of the soil profile.

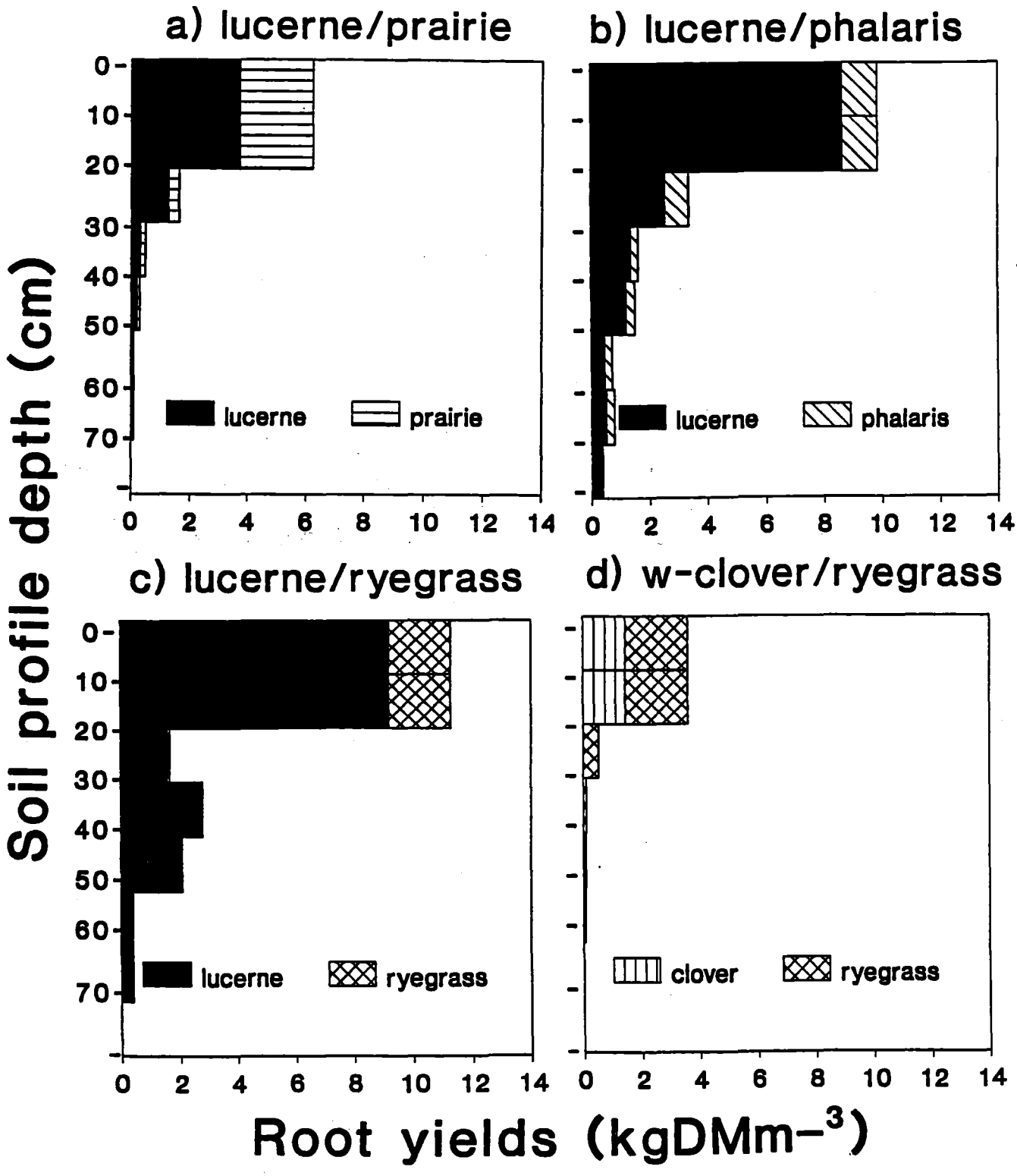


Figure 4.12 Root dry matter yields of mixed pastures of lucerne/prairie grass, lucerne/phalaris, lucerne/perennial ryegrass and white clover/perennial ryegrass at different depths of the soil profile.

4.4 DISCUSSION

4.4.1 Dry matter production and botanical composition

The effect of soil depth on production and botanical composition varied between the pastures under the very dry conditions of this experiment (Table 3.2). In the deep soils, there were no differences in the total yields of pure lucerne, lucerne/prairie grass and lucerne/phalaris, but in the shallow soils, lucerne/prairie grass yielded 3220 kg $DMha^{-1}$ less than pure lucerne compared to a reduction of only 270 kg $DMha^{-1}$ from lucerne/phalaris. Annual yields of pure lucerne in the deep soils were higher than in the shallow soils. There was no difference in lucerne/phalaris yields between deep and shallow soils. Thus it is clear that the addition of grasses did not result in increased total yields in either shallow or deep soils under dryland conditions. Earlier several authors (O'Connor, 1967; Vartha, 1973; Douglas and Kinder, 1976; Langer, 1982: Fraser; 1982) also found little or no advantage in total yield when grasses were sown with lucerne under low rainfall or unirrigated conditions. However, in deep soils, both prairie grass and phalaris did not cause significant yield reduction and may be used to provide weed control and increased winter production under more typical climatic conditions. On shallow soils, prairie grass suppressed lucerne and resulted in a large yield loss, whereas phalaris had little effect on lucerne and gave similar yields to pure lucerne. Prairie grass accounted for 55% of the total yield compared to only 15% by phalaris which indicates that prairie grass was too aggressive on shallow soils. In the deep soils, prairie grass contribution was only 26% and lucerne was the dominant component.

One of the main reasons for using lucerne/grass mixtures was to obtain complimentary seasonal production from the lucerne and grasses during warm and cool seasons respectively. The effect of soil depth on seasonal production differed between the three pastures. The seasonal yield ratio of shallow to deep soils from pure lucerne was consistently around 0.8 during the dry spring and summer and around 1.0 during autumn and winter following relief from rain (Figure 4.13a). In contrast the seasonal yield ratio of lucerne/prairie grass was as low as 0.4 during peak drought in summer and around 0.6 during spring and late summer and only arrived at 1.0 during winter. Lucerne/phalaris yield ratio was similar to pure lucerne in spring at 0.8 and marginally lower at 0.7 during summer. In autumn and winter, the yield ratio from lucerne/phalaris was above 1.2 indicating that in shallow soils, it may be beneficial to use this mixture. These ratios suggest that pure lucerne and lucerne/phalaris were least affected by the shallow soil depth even during drought, whereas

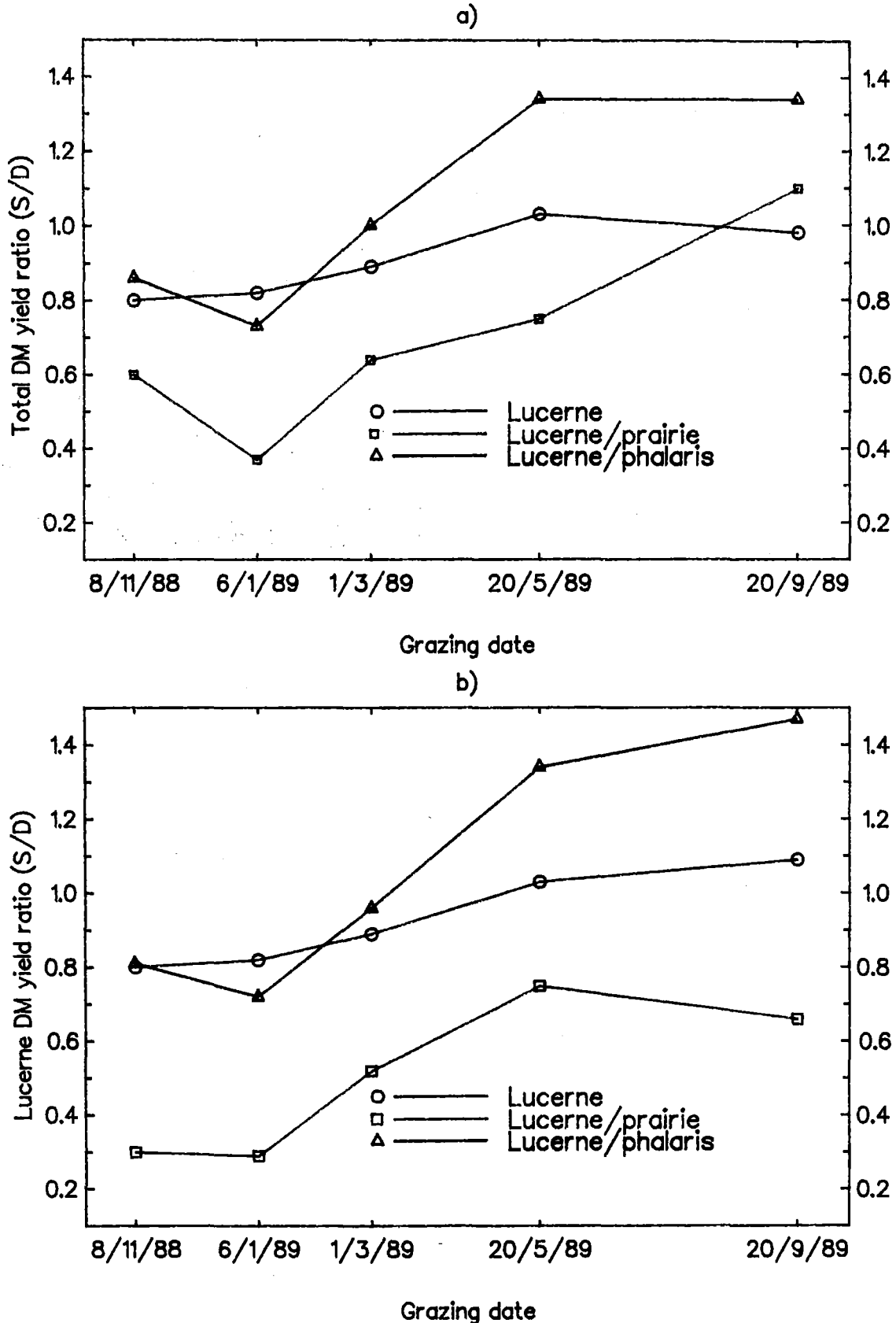


Figure 4.13 a) Total and b) lucerne dry matter yield ratios of shallow (S) to deep (D) soil at different grazing dates in pure lucerne and lucerne/grass mixtures.

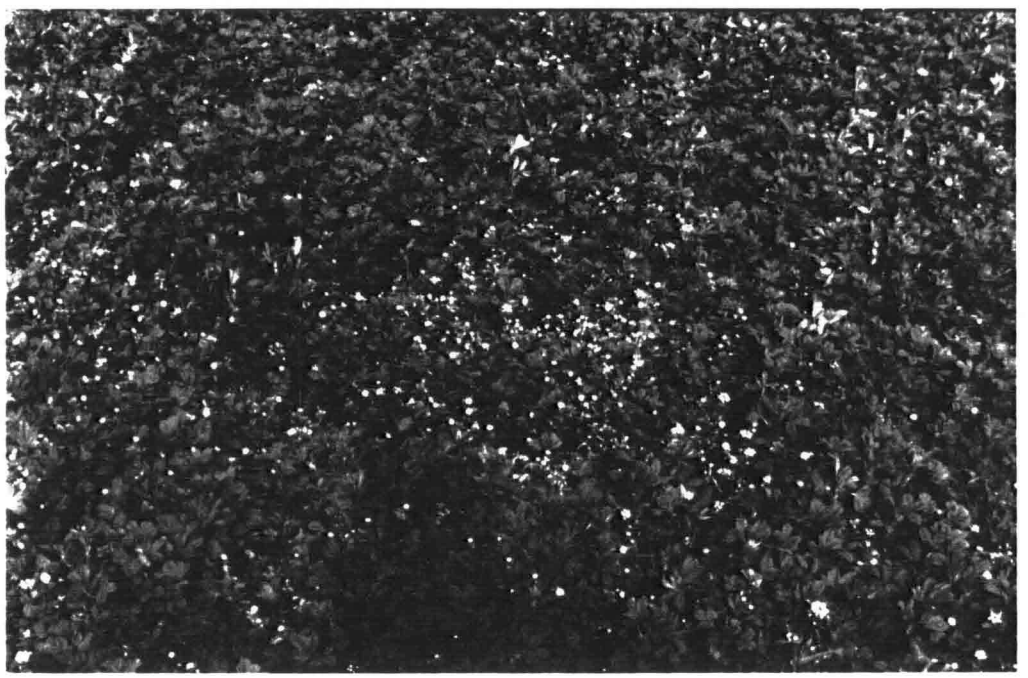
Plate 9: A lucerne/prairie grass plot showing grass dominance in shallow soils (foreground) and lucerne dominance in deep soils (background) (18/5/89).

lucerne/prairie grass was severely affected by the drought. The main reason for these differences appears to be the composition of the mixtures. Figure 4.13b shows that lucerne yield ratios of the lucerne/phalaris relate closely to the total yield ratios shown in Figure 4.13a, indicating that soil depth affected seasonal dry matter yields of lucerne/phalaris through its influence on the lucerne component. In the lucerne/prairie, prairie grass was the dominant species in the shallow soils, and therefore, the lucerne yield ratio in this mixture was different from the total yield ratio. The very low yield ratio of 0.3 to 0.6 between spring 1988 and autumn 1989 is an indication of the level of lucerne yield suppression by prairie grass in the shallow soils. The yield ratios of grasses (Figure 4.14) indicated that both performed better in the shallow soils than deep soils. In the autumn harvest following relief from drought stress, the production ratios of deep to shallow soil was 6.0 and 4.0 respectively for prairie grass and phalaris. However, the actual quantity of production from phalaris was small and therefore, despite the yields being four times higher on shallow soils, the actual difference was small.

There are several reasons for the dominance of lucerne by prairie grass in shallow soils (Plate 9). Establishment failure due to shading at seedling stage may have been a major factor. Lucerne may have been unable to develop roots which were vigorous enough to penetrate to the gravel layer below the shallow fine material. Since prairie grass has a dense shallow root system, lucerne may have been unable to compete for the surface moisture from summer rainfall and the light irrigation applications. This grass dominance would have meant that even after relief from the moisture deficit, lucerne growth was poor as a result of poor light interception, as was shown by Groya and Slayter (1973).

The seasonal yields reported in the present study are not typical of lucerne or lucerne/grass mixtures at Lincoln. Spring and summer yields were much lower and winter yields were higher than average yields reported earlier (O'Connor, 1967; Vartha, 1973; Fletcher, 1976; Fraser, 1982). Pure lucerne produced mean yields of 2420, 5120, 2110 and 3070 kg $DMha^{-1}$ in spring, summer, autumn and winter respectively in this trial whereas Fraser (1982), obtained much higher spring, summer and autumn yields of 7890, 9320, 2020 kg $DMha^{-1}$ respectively with no winter yields reported over a two year period. Earlier Fletcher (1976) reported a growing season (Sep-Mar) yield range of 10500 kg $DMha^{-1}$ on plots cut every 3 weeks to 21800 kg from those cut every 7.5 weeks. Although, regrowth periods between grazings were almost always more than 7 weeks in this study, the mean annual yield from pure lucerne plots was only 12720 kg $DMha^{-1}$.

a



b

Plate 10: A pure lucerne plot showing a) bare patches and thin stand density, and b) weed invasion (10/9/89). The most prolific weeds are chickweed (*Stellaria media* (L.) Vill.),poa annua (*Poa annua* L.) and shepherd's purse (*Capsella bursa-pastoris* (L) Medic.).

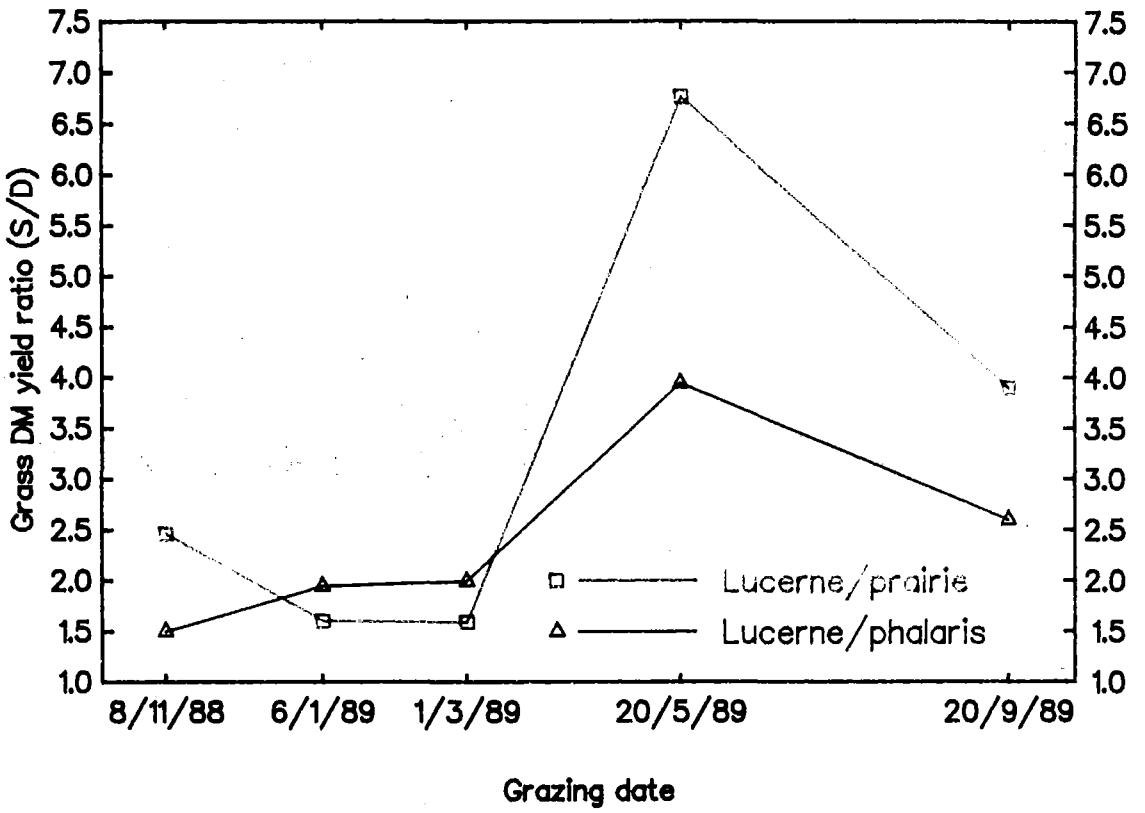


Figure 4.15 Grass dry matter yield ratios of shallow (S) to to deep (D) soils at different grazing dates in lucerne /grass mixtures.

This large reduction in yield is most likely to be the consequence of the unusually dry spring and summer followed by a warm, moist winter in the 1988/89 season (Table 3.2.). O'Connor *et al.* (1968) have shown that on drought prone soils lucerne production is positively correlated with spring and summer rainfall. The spring (Sep-Nov) and summer (Dec-Feb) rainfall during 1988/89 were only 44 and 116 mm respectively compared to the long term seasonal averages of 142 and 171 mm. Thus even after application of 120 mm of irrigation over that period, there was a deficit of 153 mm. The effects of this shortage was further compounded by the low rainfall (92 mm) in winter (Jun-Aug) 1988, which was 99 mm less than average resulting in very low soil water reserves. Mean monthly temperatures throughout the trial period were higher than normal by an average of $1^{o}C$.

Levitt (1972) showed that drought stress increases the winter-activity of lucerne. Thus the winter production from the normally semi-winter dormant cultivar WL320 could be attributed to this phenomenon. Several workers (Jones, 1980; Korte and Chu, 1983; Parfitt *et al.* 1985) have demonstrated that dry matter yields from previously water-stressed pastures were higher than those which were irrigated, following relief from stress. Lucerne was also shown to recover rapidly following water stress (Cowett and Sprague, 1972) and to give greater regrowth than previously unstressed plants (Sheafer and Barnes, 1982). Thus, in the warmer than average winter of 1989, it is likely that this compensatory production may have occurred, which is attributed to the partitioning of growth assimilates to root growth in preference to shoot during water stress (Bennet and Doss, 1970). Since high water deficits occurred in both shallow and deep soils, it was not possible to verify this effect of drought stress on subsequent production from this trial. However, the higher production from pure lucerne and lucerne/phalaris in shallow soils during winter may be indications of the drought effects.

Pure lucerne pastures had more bare patches and higher incidence of weeds than either mixtures during the winter season (Plate 10). Weeds contributed to 9% and 16% of the total winter yields of pure lucerne in the shallow and deep soils respectively. Both lucerne/prairie grass and lucerne/phalaris had good ground cover and weed yields were below 3% (Plate 12), indicating that they are capable of controlling weed ingression, and thereby improve the quality of winter herbage and prevent deterioration of lucerne pastures.

a

b

Plate 11: Lucerne/grass plots showing good stand density and weed control: a) lucerne/prairie grass and b) lucerne/phalaris (10/9/89).

4.4.2 Water use and water use efficiency

There were no differences in cumulative or seasonal water use (ET) between the pure lucerne and the lucerne/grass mixtures (Table 4.5). During the dry spring and summer, the very high soil water deficits may have eliminated any differences between the pastures in their rate of ET. Once the drought was broken by autumn rain, pure lucerne used marginally higher amounts of water. Blad and Rosenberg (1974) reported that ET from a lucerne/*poa pratensis* pasture was 20-25% less than pure lucerne while others (Chamblee, 1958; Snaydon, 1972) were unable to show much difference between lucerne and other pastures.

The effect of soil depth on water use relates well to its effects on dry matter yields. During the dry spring and summer, water use was higher in the deep soils suggesting a higher quantity of available water. When moisture deficit was not limited in autumn and winter, there were no differences in water use between the shallow and deep soils. Similar results were reported by Sherrel (1986) who studied the water use of lentils on different soil depths at the same site and showed that when irrigation was applied to maintain adequate soil moisture, lentils used similar amounts of water regardless of soil depth.

Snaydon (1972) showed that evapotranspiration from summer-active and summer-dormant pastures was similar even during summer. Thus although phalaris was dormant during summer, water use from lucerne/phalaris did not differ from summer active pastures of pure lucerne or lucerne/prairie grass. As stated earlier, there was very little stored water at depth because of the dry preceding seasons. Most of the water use measured came from the top 30 cm of the soil (Figures 4.9 & 4.10) which originated from the infrequent summer rainfall and the light irrigation applications. Under similar dryland conditions in Australia (annual rainfall <600 mm), Snaydon (1972) found that less than 15% of summer evapotranspiration was supplied from the soil water store. Thus despite the deep roots and potentially higher water use ability of lucerne, ET measured during dry seasons remained similar being dependent on current rainfall and irrigation.

Powell and Kardos (1968) observed that lucerne/brome grass and lucerne/cocksfoot mixtures differed only slightly from pure lucerne in water use efficiency. When each was grown separately, lucerne was more efficient than either brome grass or cocksfoot. In another study by Cohen and Strickling (1968), lucerne used up approximately the same amount of water (15 kg $DMha^{-1}mm^{-1}H_2O$) during the growing season as tall fescue. Since there were no

pure prairie grass or phalaris pastures in this trial, it is not possible to compare the water use efficiency of lucerne and these two grasses directly. However, it can be inferred that lucerne had a higher WUE because the pure lucerne and the lucerne dominant pastures of lucerne/phalaris, in both shallow and deep soils, and lucerne/prairie grass in the deep soil, gave higher WUE than the grass dominant pasture of lucerne/prairie grass in the shallow soil.

The mean WUE of pure lucerne at 25kg $DMha^{-1}mm^{-1}$ H_20 was higher than the mean value of 14-17 kgDMha-$1mm^{-1}$ H_20 reported in USA (Heichel, 1983). Water stress was often reported to increase WUE in plants because of stomatal resistance to water loss which results in any reduction in yield being accompanied by a greater reduction in water loss (Rawson *et al* 1977). The effects of water stress on WUE of lucerne are not clearly defined. Donovan and Meek (1983) found that WUE decreased in both dry and wet irrigation treatments compared with optimally irrigated lucerne. Reduced WUE in non-irrigated lucerne was reported by Carter and Schaeffer (1983) who also observed that WUE of lucerne increased under low irrigation during cooler growing conditions in autumn.

In a greenhouse experiment, Fairbourne (1982) measured a WUE range of 12 to 15 kg $DMha^{-1}mm^{-1}H_20$ from lucerne depending on cultivars, 17 kg from tall fescue and cocksfoot, and 14 kg from brome grass under well watered conditions showing that grasses generally have similar or greater WUE than lucerne. Cohen and Strickling (1968) showed that the WUE of bermuda grass (*Cynodon dactylon*) under high N application of 180 $kgha^{-1}$ (24 kg $DMha^{-1}mm^{-1}H_2O$) was more than twice that of low N application of 45 $kgNha^{-1}$ (11 kg $DMha^{-1}mm^{-1}H_2O$) demonstrating that the WUE of grasses are highly influenced by soil fertility.

It may be possible that the high WUE from lucerne in this trial may have risen from the underestimation of water used by lucerne. Lucerne is capable of using water from below the fine material layer of the soil (Hayman and Stocker, 1982), which was not measured in this trial. In any case, the very low WUE of lucerne/prairie grass in the shallow soils during summer drought (10 kg $DMha^{-1}mm^{-1}$), indicated that interspecific competition between lucerne and prairie grass for the scarce surface moisture results in a net reduction of WUE.

4.4.3 Water extraction rooting patterns

The water extraction patterns (Figures 4.9 and 4.10) showed very small differences between the pastures. In the shallow soils, significant extraction occurred under all pastures until the water content reached about 15 mm at the 20 cm depth and below 10 mm at 30 and 40 cm depths. Since significant changes in soil water content occurred at the 40 cm depth when soil moisture was not limiting, it can be assumed that all pastures (pure lucerne and phalaris, mixed lucerne/prairie grass and lucerne/phalaris) were able to extract water from below the depth of measurement, i.e. from the gravelly sub-soil layer. This was demonstrated by Hayman and Stocker (1982) who found that on the stony Eyre soil, 32% of the deficit under pasture and 40% of the deficit under lucerne came from the gravel sub-strata.

In the deep soils significant extraction from pure lucerne occurred up to the 1 m depth measured and it can be assumed that further extraction occurred from below this depth. In pure phalaris, lucerne/prairie grass and lucerne/phalaris, significant extraction occurred only up to 70 cm depth and at 80 cm depth there were no changes in soil water content between the different measurement dates even when the soil moisture was adequate in the early spring. Thus it seems that the water extraction ability of lucerne from deeper layers of the soil profile was reduced by the inclusion of grasses and this may partially explain the lower dry matter production of the mixtures during drought. This suggests that in order to allow the lucerne to establish a deep root system, grasses should be over-drilled into already established lucerne rather than by mixed sowing.

The lucerne/phalaris mixture used up soil moisture more rapidly than lucerne/prairie grass by reaching the soil water content at which point no further extraction occurred at the second fortnightly measurement (Figure 4.10). Lucerne/prairie grass reached the limiting deficit at the third fortnightly measurement. This may have been due to the different composition of roots in these mixtures. As shown in Figure 4.12, the lucerne root masses at all depths sampled were less in the lucerne/prairie grass than in the lucerne/phalaris and could have been responsible for the slower water extraction. The water content at which plants were unable to extract further water seems to be relatively uniform for all the pastures, that is at 10 mm per 10 cm layer or 10% by volume of soil. For practical purpose, the results indicate that if soil moisture in the top 0-20 cm depth is gravimetrically determined, it would be necessary to irrigate the above pastures when water content approaches 20 mm. Likewise, if a neutron probe is used, water should be supplied before moisture content from 20 cm downwards drops

to below 10 mm per 10 cm layer (if moisture content was determined at 10 cm intervals as in this experiment). Thus, for a fine sandy loam soil with a profile depth of 1 m and field capacity of 250 mm, the limiting deficit is 150 mm (250mm - 10mm x 10).

More meaningful results would have been obtained if the initial soil water content at the beginning of the measurement was higher and if more frequent measurements have been made (refer Section 4.4.4). Since the water deficit became limiting for all the pastures by the second or third set of measurements, it was not possible to follow up further extraction patterns. In any case, water extraction pattern studies without a rain shelter may be confounded by rainfall events. Further research needs to be carried out preferably under rain shelters and high initial soil moisture content.

4.4.4 Experimental design and techniques

The trial was carried out using an unconventional, improvised design and therefore the results need to be interpreted in the light of some drawbacks with the design and techniques used. The survey of the trial site to find deep and shallow areas was made with a motorised corer. Due to the extremely dry soil conditions at the time of augering, the process was very tedious and time consuming, and hence limited the number of auger holes drilled. Variation in soil texture at different layers was not recorded. This would have been useful in explaining the variation in yield and water use. A more systematic survey such as augering at 10 m X 10 m grid intervals with additional records on soil textural variation at various depth could have given a more accurate soil map.

Another major technical drawback was the depth of neutron access tube installation. Neutron probe access tubes could not be installed into the gravel layer by drilling access holes with a power auger. Hence the water use measurements reflect only the amount of water measured above the gravel layers, and thereby may have resulted in underestimating the actual water use. Hayman and Stocker (1982) installed the neutron access tubes by driving a pointed solid rod of the same diameter into the ground to prepare the access holes. The same method could not be used in this trial because of the extremely dry conditions which made it difficult to hammer in a rod, and would have been very time consuming because of the large number of tubes used. In their study, Hayman and Stocker (1982) had only 4 neutron access tubes.

The area of deep soil under the lucerne/prairie grass was not large enough to accommodate 8 plots and thus only 4 replicates for each soil depth under this pasture could be located compared with 8 replicates for pure lucerne and lucerne/phalaris. This unequal replication could have resulted in a lower level of accuracy in the data for lucerne/prairie grass, and needs to be taken into consideration when drawing comparisons between the pastures.

The time input required to measure the water content of the 40 experimental tubes and an additional 8 tubes on pure phalaris pastures (located in the raceway) using the neutron probe was very high taking at least 8 hours to complete one set of measurements. This work input included gravimetric sampling of the top 0-20 cm layer of the soil profile near every tube. Quite often, measurements collected over several hours had to be discarded as a result of interruption from rainfall which alters the neutron readings. Thus a smaller number of tubes with more frequent measurements than the fortnightly schedule used in this trial could have been a more practical and reliable technique.

An additional source of error in the determination of water content could have been caused by the compaction of soil sample for gravimetric determination. Since the soil surface was very dry during the spring and summer periods, the soil auger had to be forced into the soil with a hammer, thus resulting in soil compaction which would have altered the bulk density of the soil, and therefore influenced the calculation of gravimetric water content.

The relative water use of lucerne and the grasses could not be determined, nor could the extent of competition for water between the grass and the lucerne components in the mixture be quantified, since there were no pure plots of prairie grass and phalaris under similar treatments. The data from the pure phalaris plots on the raceway were used only for determining the water extraction pattern of pure phalaris, since the different grazing management, as well as the effects of stock and machinery movement on the raceway, made herbage measurements highly variable.

The auger method used in this trial to measure the root mass and distribution at various depths of the soils posed several problems. For instance, placing the cutting edge of the auger directly on top of the lucerne crown, results in extracting only the tap root and thus overestimates the root mass per unit of soil volume. On the other hand, placement in between the plants results in underestimation of root mass as only fine roots are collected in the sample. A similar problem was encountered when sampling the roots of the lucerne/grass mixtures.

Sampling from lucerne rows gave only lucerne roots and from grass rows, only grass roots. If the sample was taken from the middle of the rows, grass was favoured because of its more fibrous and branched root system. Thus the method adopted in this trial of taking a sample from each row as well as a third from between the rows may have only partially eliminated this problem. However, given the time and labour constraints in conducting this study, it was probably the most suitable method.

Finally the plots were selected subjectively based only on soil depth and visual observation of vegetation to avoid urine patches, stock camps, and uneven lucerne/grass proportions. No account was taken of variations in soil fertility, texture, and drainage. Neither was the variation in animal effects during the trial period such as selective grazing, tramping, camping and distribution of excreta monitored.

Despite the above limitations, this study has provided useful information on the relative merits of lucerne and mixtures of lucerne with prairie grass or phalaris. While further research is necessary under a more typical climatic condition in the region than that experienced during 1988/1989, the results have highlighted some basic differences between prairie grass and phalaris in their sociability with lucerne.

CHAPTER 5

GENERAL DISCUSSION AND CONCLUSIONS

5.1 ROLE OF LUCERNE/GRASS MIXTURES

The lack of yield advantage from lucerne/grass mixtures over pure lucerne under dryland conditions has long been acknowledged (O'Connor, 1967; Vartha, 1973; Langer, 1982). Inspite of this knowledge, the use of winter-active grass species in association with lucerne, has been actively promoted to enhance winter production, prolong lucerne stand life and control weed ingression into pure lucerne pastures (O'Connor, 1967; Vartha, 1970; Fraser, 1982, 1983; Langer 1982). The release of highly winter-active 'Grasslands Matua' prairie grass and 'Grasslands Maru' phalaris have greatly enhanced not only the possibility of lucerne/grass mixtures in fulfilling the above roles, but also that they may provide increases in herbage yields.

In an earlier evaluation by Fraser (1982), lucerne/Matua gave consistently good seasonal spread of production over a two year period and produced 2390 kg $DMha^{-1}$ more than pure lucerne in the second year. In the present study, neither annual yields nor seasonal yields of the mixtures were significantly higher than pure lucerne. Figure 5.1. shows the yields of pure lucerne, lucerne/prairie grass and lucerne/phalaris at different harvests between 1987 and 1989 from the grazing duration experiment. Apart from the harvests of October 1987 and November 1988, when lucerne/prairie gave higher yields than pure lucerne, there were little differences between the different pastures. Total dry matter yields of both pure and mixed pastures were much lower than those reported by Fraser (1982) due to the very low rainfall and the shallower soil conditions in the present study.

The productivity of dryland lucerne and lucerne/grass mixtures is clearly dependent on annual rainfall and therefore also upon the soil moisture content (Table 5.1). In dry years (annual rainfall <700 mm), pure lucerne and lucerne/grass mixture yields were similar but in a wet year (annual rainfall >700 mm), lucerne/grass mixtures gave higher yields. The light irrigation (150 mm) applied during the summer of 1988/89 was not sufficient to compensate the lack of adequate stored soil water at depth as a result of the low rainfall during the preceding winter and spring 1988.

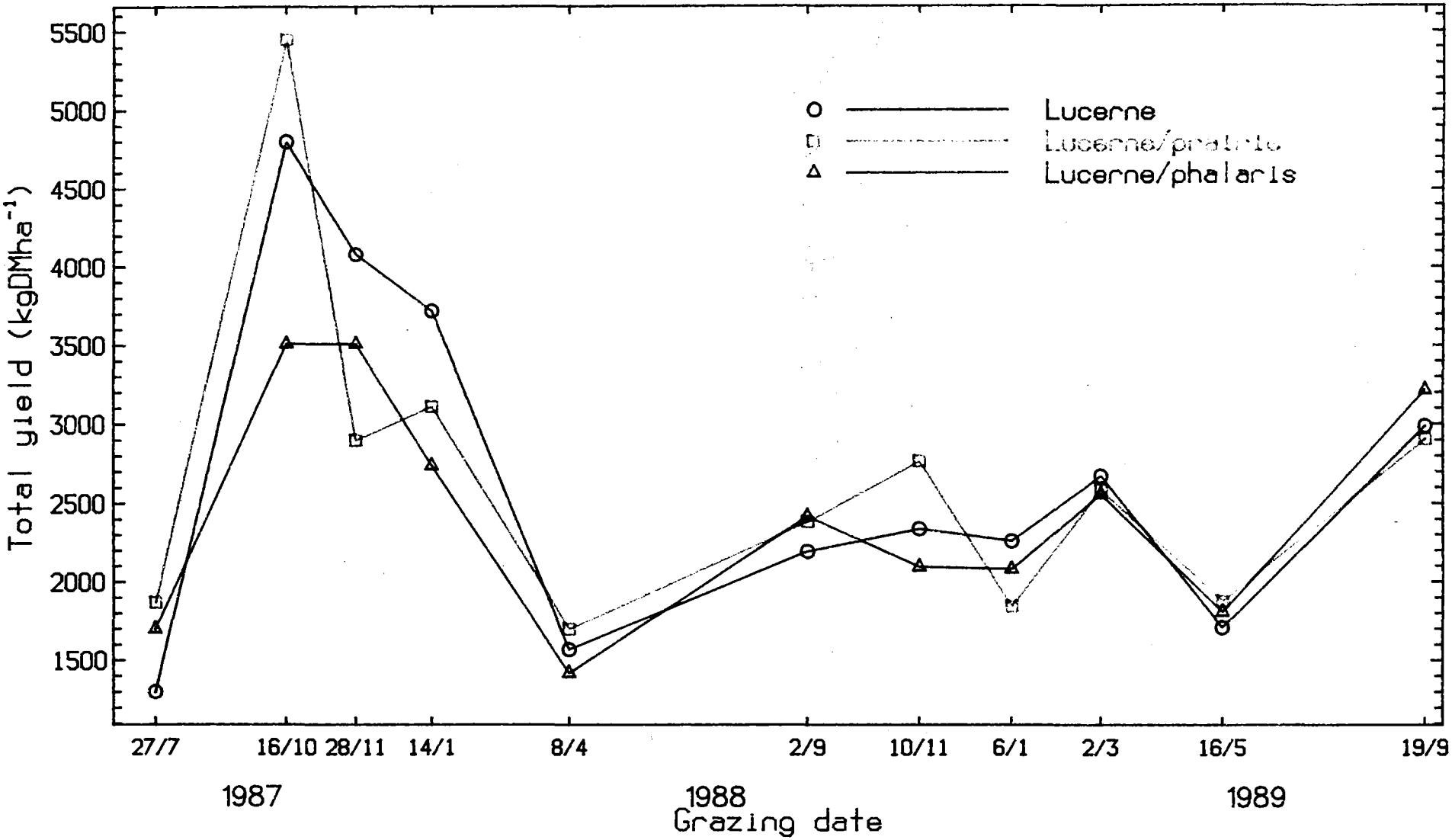


Figure 5.1. Total yields of lucerne and lucerne/grass mixtures at different grazing dates between 1987 and 1989. (Data for 27/7/87–14/1/88 from Xu (1989) and 8/4/88 from Pownall (pers. comm.))

Table 5.1 Effect of annual rainfall on the productivity of lucerne and lucerne/grass mixtures.

Year	Rainfall (mm)	yield kg DMha^{-1}yr^{-1}		
		Lucerne	Luc/Matua	Luc/Maru
1976-77*	696	19540	19030	17210
1977-78*	795	18550	22370	18550
1987-88**	583	13900	13330	12710
1988-89***	491	11960	11980	11760

Source:

* Fraser (1982)

** Xu (1989)

*** Grazing experiment excluding September 1988 harvest.

Variation in rainfall not only affected dry matter yields but also the seasonal growth pattern of lucerne and grasses. During the 1988-89 dry year, lucerne continued to produce during the winter whereas in the 1977-78 wet year, lucerne remained dormant during the winter. This was probably due to the warm and moist winter of 1989, and to the higher soil temperatures resulting from the hot dry summer as well as the different cultivars being used (Section 5.2). Regardless of the annual rainfall, pure lucerne yields were almost always higher than the lucerne/phalaris mixture. Thus an ideal lucerne/grass mixture which will give good all-year round production and higher yields than pure lucerne can only be achieved if lucerne is grown with prairie grass in areas with reliable annual rainfall or with irrigation. In dryland areas with low or unreliable rainfall, the role of lucerne/grass mixtures appears to be restricted to controlling weed ingression and probably to prolonging the stand life of pure lucerne through over-drilling when pure lucerne thins out to about 60% ground cover.

5.2 CHOICE OF COMPANION GRASS SPECIES

O'Connor (1967) outlined the desirable characteristics of a good companion grass as one that has good winter and spring growth but does not dominate lucerne during summer and is not completely dominated by lucerne. This is, however, a simplistic statement, since the effects of climate, soil type and cultural practices such as the establishment method and grazing management must be considered. Grasses and lucerne behave differently in mixed stands and pure stands as a result of interspecific competition and hence their agronomic potential in pure stands may not be obtained in mixed pastures. Thus several other qualities are required in a companion grass in order to obtain a balanced mixture.

The drought resistance of a companion grass is important. Lucerne is particularly well adapted to dry conditions and is only grown in drought prone areas of New Zealand. For this reason, a companion grass must also be able to survive drought. Generally, lucerne growing areas in Canterbury and Otago are characterised by shallow soils with low soil moisture storage capacity. Companion grasses must therefore be able to penetrate subsoil layers to survive through drought. Beside soil moisture status, soil nutrients may limit production as a result of increased competition between the lucerne and grasses especially for S, K and P during establishment (O'Connor, 1967). Nitrogen fixation by lucerne and consequent transfer to the companion grass will be poor in drought stressed lucerne and thus grasses may suffer from N deficiency. It is essential therefore, for companion grasses to be adapted to low soil fertility.

The associate grass should be tolerant to shading and conversely should not shade lucerne as lucerne is very sensitive to shading (Brown and Blaser, 1968). Reduced interception of light causes yield reduction and inhibits lucerne nodulation (Pritchett and Nelson, 1951). Fast growing grasses suppress lucerne seedlings while slow growing grasses are suppressed by the lucerne. Similarly defoliation practices to suit lucerne growth, may not favour the grass component as the light regime is altered. In pure pastures, fast regrowth from grasses is desirable, but in mixtures, this may depress lucerne shoot regrowth as a result of shading. Conversely, grasses with slow regrowth may be shaded out by lucerne.

In addition the quality of the companion grass in terms of palatability and nutritive values needs to be considered. Grasses should be readily eaten and should have a high nutritive value without having toxic effects on stock. When lucerne/grass mixtures are

managed to give optimum spelling times for lucerne, grasses may become "over mature" and become less palatable and nutritious than thevegetative growth from frequent grazings (Lucas, pers. comm.). This aspect is especially critical in winter when the herbage will consist of a high proportion of grass. Pest and disease resistance is another important characteristic, since they influence the quality as well as persistence of the grasses.

While much more research is required in selecting companion grasses, establishment and grazing management of lucerne/grass mixtures, the present grazing and soil depth studies have contributed substantially to a better understanding of the effects of climate, soil type and grazing management of lucerne/prairie grass and lucerne/phalaris mixtures, and their relative advantages over pure lucerne. Useful inferences from the method of establishment can also be drawn on the two grasses studied.

5.2.1 'Grasslands Matua' prairie grass

Matua prairie grass was bred for use on high fertility dairy farms (Rumball, 1974) but has been shown to survive well through drought and give high autumn and winter production (Langer, 1982; Fraser, 1982; Lancashire and Brocke, 1983). Fraser (1982) obtained three times more winter production from pure stands of Matua than from Nui ryegrass. Matua is considered to be palatable at most times of the year, even the mature seed heads being readily eaten by sheep (Langer, 1982). Fraser (1982) showed that Matua complemented lucerne production favourably over the two year period and produced higher annual dry matter yields than pure lucerne in the second year following sowing. Matua accounted for an average of 92% in winter, 70% in spring, 32% in summer and 42% in autumn, of the total production from lucerne/prairie grass mixture. Similar seasonal distribution was not obtained in the present trial since the lucerne and prairie grass components both produced throughout the year irrespective of season (Tables 3.9, 3.11, 4.3 and 4.4).

There are several reasons which may have caused the difference in performance of lucerne/Matua mixtures in Fraser's (1982) and the present studies. The extremely dry conditions in 1988/89 (Table 3.2) with little subsoil moisture reserve meant that lucerne had to compete for surface moisture with Matua in both spring and summer. Since Matua has a high concentration of roots in the top 30 cm of the soil profile (Figure 4.12), it used up any moisture from the occasional light rainfall and irrigation, enabling it to maintain a high degree of summer activity at the expense of lucerne. Conversely, the dry summer conditions followed by

a warmer than normal winter, induced lucerne growth during winter thus suppressing winter production from Matua. Fraser's (1982) trial was evaluated under a cutting regime, which would have favoured grass growth because of the instant defoliation. Under grazing defoliation occurs gradually and over a period of time which may favour lucerne as new grass tillers become susceptible to repeated defoliation before lucerne basal shoots emerge. Moreover, under a cutting system, animal effects through diet selection, tramping and distribution of excreta will not be present. One of the main objectives of growing lucerne/grass mixtures must be to utilise them as grazed pasture and therefore evaluations other than under grazing are of limited practical value. Nevertheless, the criteria used by Fraser (1982) for timing the harvests, i.e. at early flowering stage of lucerne in warm seasons and late vegetative stage of grass in cool seasons, may provide an important strategy for manipulating the lucerne/Matua balance in the mixtures and needs further research under grazing.

The effect of seasonal variation in rainfall on the productivity of Matua relative to lucerne in the mixture is evident from yield differences between the two years of Fraser's (1982) experiment. Matua produced 48% of the lucerne/Matua yield in a wet summer (224 mm rainfall), but only 17% in a dry summer (<112 mm rainfall). This indicates that Matua may probably dominate lucerne if successive seasons were wet. Evidence from the present study shows that soil depth and hence the water holding capacity will determine the composition of lucerne/Matua mixtures in dry years. In shallow soils, Matua was dominant and lucerne contributed to only 65% of the yield even during the summer (Figure 4.6). Total yields were reduced as a result since the higher grass growth in winter (Appendix 5) was not sufficient to compensate for the yield loss from lucerne during summer and spring. On the other hand, in deep soils, lucerne was the dominant component even during winter which limited the production from Matua, thus conflicting with Fraser's (1982) results on Wakanui silt loam soils. It appears that lucerne in the present trial depended as much on summer rainfall and irrigation for growth and survival as did Matua, and was therefore more competitive in deep soils than on shallow soils due to the more favourable rooting conditions. Matua is thus not a suitable companion grass for lucerne in shallow soils. However, in deep soils, Matua may complement lucerne growth, although productivity will depend on the amount of current rainfall as indicated by the lower water use efficiency of the lucerne/Matua mixture during the dry seasons than in winter when moisture was adequate (Table 4.6).

The grazing management required by Matua for maximum production may suppress lucerne growth. Langer (1982) recommended break feeding prairie grass and Clarke (1985)

suggested a two day grazing duration. This short duration grazing may lead to shading of lucerne and alonger grazing duration is proposed to reduce the competition for light following grazing (Langer, 1982; Moot, 1986). The results from the present experiment showed that Matua production was reduced under long grazing but that the length of grazing duration did not affect lucerne productivity. The short grazing duration treatment of 3-7 days yielded 2420 kg $DMha^{-1}$ more Matua than the long duration treatment (Table 3.11), but decreased lucerne yields by only 690 kg $DMha^{-1}$ (Table 3.9). Similar results were obtained by Xu (1989) from his work on the same trial during 1987/88. However, Xu (1989) interpreted the higher proportion of Matua dry matter yield under short grazing as indications of grass dominance and supression of lucerne. Even if the higher proportion of Matua relative to lucerne under short grazing may imply that continual short grazing may eventually suppress lucerne, it can be equally argued that long duration would probably reduce prairie grass productivity and persistence. The best compromise therefore, appears to lie in having a flexible grazing duration regime with short grazing durations in autumn and winter to stimulate Matua production during the cool season, and longer grazing duration in spring and early summer to decrease Matua vigour and encourage lucerne dominance. This grazing management regime needs to be examined preferably in association with different spelling treatments. In any case, there is a need to quantify the minimum ratios of lucerne and grass in order to plan an appropriate management strategy to favour either the lucerne or the grass component whichever is desired. For example, if lucerne proportion falls below 40% other than in winter, management should favour lucerne growth and similarly, if grass content in the mixture falls below 40% except in summer; then grass should be favoured .

Brown (1989) studied the regrowth of tillers following grazing and found that Matua tillers were 25% longer under short grazing, 44 days after grazing in autumn but that long duration gave higher tiller numbers. Thus, there occurred a degree of compensation between tiller length and tiller numbers and the net effect on herbage production was small. Lucerne shoot numbers were not affected while shoot length was higher in the short than in the long grazing duration treatments indicating that contrary to popular theory, lucerne was not shaded by Matua under short grazing. Brown (1989) attributed this effect to the higher carbohydrate reserve accumulated by lucerne under short grazing duration because of the longer recovery periods. However, these effects of grazing duration on Matua and lucerne regrowth may not be the same during other seasons and therefore warrant further investigation.

An alternative approach to alter the proportion of Matua in lucerne/grass mixtures may be by manipulating the intensity of grazing. Black and Chu (1988) compared the performance of Matua under lax (2000 kg $DMha^{-1}$ residual herbage mass) and hard (1000-1250 kg $DMha^{-1}$) grazings. They found that although lax grazing maintained sward persistence, it resulted in poor utilisation (50%) of pasture. Hard grazing normally declined sward persistence but can improve pasture utilisation (75%) without affecting sward persistence, if grazing is delayed until new replacement tillers have appeared. Thus in lucerne dominant pastures, it may be possible to increase Matua proportion by either lax or delayed hard grazing. Accordingly Matua dominance can be reduced by hard grazing before appearance of new tillers at the base of the sward.

The shading of lucerne by Matua at the seedling stage (Xu, 1989) may have caused the poor performance of lucerne in the shallow soil sites on this trial. Over-drilling Matua in late summer to early autumn after sowing lucerne in spring may overcome this problem since lucerne roots would have been well developed to compete favourably with Matua. Preliminary results from September over-drilling of Matua, Maru and Nui showed that Matua established readily and began to dominate lucerne four months after sowing under both irrigated and dryland conditions (Ayalsew, pers. comm.). However, this was obtained under a very high seeding rate (equivalent to 68 $kgha^{-1}$) and a lower seeding rate may have been less competitive. Further research with different times of over-drilling and different seeding rates may be required to resolve this issue.

Another aspect of Matua that is as yet not clearly understood, is its competition for nutrients with lucerne. Being bred for high fertility soils, Matua may give low production over a period of time when soil fertility becomes depleted especially in shallow soils, where it dominates lucerne. The rapid rate of regrowth and potentially rapid year-round growth would demand high inputs of nutrients especially N. The early suppression of lucerne would result in reduced N_2 fixation and transfer from lucerne. Matua plants in the non-urine patches of this trial appeared to be yellowish and showing symptoms of N deficiency. This aspect needs to be studied as well as the use of nutrients to manipulate lucerne/grass balance; for example, the use of S, K and P to stimulate lucerne growth in summer or N to encourage grass growth in winter whichever is desired.

Matua is susceptible to head smut (*Ustilago bullata* Berk) which has been the cause of failure of lucerne/Matua mixtures in some earlier trials (Vartha, 1973; Moot, 1986). Falloon

(1980) reported that head smut reduced Matua herbage yields (12-50%), tiller numbers (16%), and seedling survival. At Ashley Dene, Moot (1986) reported that Matua was severely affected by head smut and as a consequence, the lucerne/Matua mixture was the least productive of all the lucerne/grass mixtures tested which included lucerne/ryegrass, lucerne/cocksfoot and lucerne/phalaris.

Considering all the above pros and cons, it is clear that under dryland conditions, Matua may perform well in association with lucerne only in deep soils with good soil moisture status, where there is no incidence of head smut, and providing that appropriate methods of establishment and grazing management are used.

5.2.2 'Grasslands Maru' phalaris

Phalaris has been grown for many years in New Zealand, but poor establishment, low germination and the lack of a locally adapted cultivar have prevented its widespread use (Rumball, 1980). 'Grasslands Maru' has been bred to overcome these problems. The main growth periods of Maru are autumn, winter and early spring (Lancashire and Brock, 1983). It was reported to remain dormant in summer and recover rapidly in autumn following relief from drought and decline in temperature (Rumball, 1983). From a series of trials in Taupo, Wairarapa, and Southland, Stevens *et al.* (1988) reported that Maru is well suited for dry hill country being particularly productive in spring and summer. Compared to Nui ryegrass, it provided more flexibility to variations in management and soil fertility and effectively reduced grass grub numbers. These qualities have led many workers to suggest that Maru be a promising companion grass for lucerne (Rumball, 1983; Moot, 1986; Xu, 1989).

Evaluation of Maru in mixtures with lucerne has so far not been very encouraging. Fraser (1982) obtained good spring and autumn growth but winter growth of Maru in mixtures with lucerne was very poor averaging only 350 kg $DMha^{-1}$ compared to 1440 kg $DMha^{-1}$ in pure stands during the two year period. Xu (1989) obtained a winter yield of 1320 kg $DMha^{-1}$ in the first winter following October sowing. Winter yields obtained from the present experiment were 830 and 800 kg $DMha^{-1}$ in 1988 and 1989 respectively (Table 3.11 & 4.4). The extremely poor winter performance of phalaris in Fraser's (1982) trial may be in part due to the very low seeding rate of 1.5 kg used, but good performance in spring of the first year and spring and autumn of the second year suggests that factors other than poor establishment were responsible. Besides the reasons discussed in Section 5.2.1, it could have been caused by the

the harvesting criteria used during cool season. Harvests were made whenever the higher yielding of Matua and Maru was considered to be at maximum yield. Since prairie grass was faster growing and therefore faster maturing, Maru would have been disadvantaged and harvested at a less mature stage.

Although Maru phalaris yields were higher in this trial, winter production was considerably less than Matua and Maru's contribution to annual yield was only about one third that of Matua. The performance of Maru appears to be unaffected by variation in rainfall. Fraser (1982) showed that in both a dry and wet year, Maru production patterns were similar. Thus soil moisture does not appear to influence phalaris performance directly when grown with lucerne and is probably more related to suppression by lucerne through shading. The soil depth results support this assumption as phalaris yields were not affected by variation in soil depth and therefore, not affected by moisture availability when grown with lucerne. On both shallow and deep soils, lucerne dominated phalaris and the lucerne/phalaris mixture was therefore able to produce similar yields to the pure lucerne. This was probably because of its deep rooting characteristic (Figure 4.12) which forces it to compete with lucerne for water and nutrients in the same zone of the soil profile. Lucerne regrowth rate was faster than phalaris and it may have intercepted more solar radiation enabling it to utilise the moisture and nutrients more effectively than phalaris. Thus the advantages of phalaris remaining dormant during summer and allowing lucerne to achieve maximum production are undermined by its inability to perform well during winter.

Phalaris also appeared to be as insensitive to grazing duration treatments as it was to soil depth. There were no significant differences in Maru yields between the short and long grazing duration treatments except in winter 1988 and late summer 1989, when long grazing duration produced more than short duration (Table 3.12). Brown (1989) observed higher shoot failure of lucerne (283 shoots m^2 failed to persist) under long duration compared to short grazing duration (150 shoots m^{-2}). This may have led to less competition for light from lucerne and probably more nitrogen cycling in the soil assisting phalaris growth under long duration grazing. Moreover, Maru recovered very slowly in autumn following summer drought and was subjected to shading by lucerne under short duration (Brown, 1989). It appears therefore, that a different grazing schedule to that recommended for lucerne/Matua (Section 5.2.1) may be required for lucerne/Maru. Short grazing durations in spring and summer to maximise lucerne production, and long grazing durations in autumn and winter to encourage phalaris production should provide a suitablegrazing management strategy for

lucerne/Maru mixtures. Once again, this needs to be investigated in conjunction with the criteria for initiating grazing based on plant maturity.

Water use by pure lucerne and lucerne/Maru was similar (Table 4.5) which suggests that Maru offered little competition for water to lucerne. Since lucerne was the dominant component, it can be assumed that water was mostly utilised by lucerne in the lucerne/phalaris mixture. There was no difference in water use efficiency between the pure lucerne and the lucerne/phalaris either during the spring and summer drought period or in good soil moisture conditions in autumn and winter (Table 4.6).

Establishment method appears to have little effect on the persistence of Maru in the mixture. Both Fraser (1982) and Xu (1989) obtained satisfactory establishment from direct sowing with lucerne in spring irrespective of seeding rates. September over-drilling into vigorous mature lucerne was not successful and Maru seedling survival was found to be poor in both irrigated and unirrigated plots (Ayalsew, pers. comm.). In contrast an early September over-drilling into a deteriorating lucerne stand following spraying with glyphosate in August, was found to be very successful (Lucas, pers. comm.) Scott and Maunsell (1981) suggested that slow establishment of Maru meant that its true potential may not be expressed until two years after sowing. This suggestion was not supported by the findings from this trial although Moot (1986) reported that Maru was the best of several grasses tried at Ashley Dene after seven years and not only excluded weeds but also legumes. This difference may probably be due to the grazing regime adopted in the present trial which was aimed to suit lucerne growth.

As yet, little work has been done in New Zealand on the palatability and toxicity of phalaris. Against the desire for higher production from phalaris, consideration must be given to the effects on animal production and animal health at high phalaris proportions. Harris (1982) showed that Maru palatability was low but Moot (1986) reported from observations at Ashley Dene, that Maru was readily eaten by sheep and that even the hollow inflorescence stems were more palatable than prairie grass, ryegrass, cocksfoot and barley grass. Maru is reported as having a lower alkaloid concentration than other phalaris cultivars, and phalaris staggers caused by long term feeding to sheep can be prevented by cobalt treatment (Rumball, 1980). It is resistant to grass grub (*Costelytra zelandica*), Argentine stem weevil (*Listromotus bonariensrs*) and black beetle (*Heteroncylus arator F.*) and therefore should persist for many years.

Until the problem with lucerne dominance is resolved, there appears to be little justification for sowing Maru with lucerne under dryland conditions apart from controlling weed ingression. However, because of its potential persistence, Maru may gradually become more competitive as the lucerne ages and starts to decline in vigour and may provide longer stand life than lucerne/Matua mixtures as the latter may not persist longer than 4 or 5 years.

5.3. CHOICE OF LUCERNE CULTIVARS

It is generally assumed that the use of a winter dormant lucerne cultivar will provide the basis for a good lucerne/grass mixture since it will not compete with the winter-active grass companion during cool seasons. Lucerne is dormant in its true form but most New Zealand cultivars have an infusion of *Medicago falcata L.* which results in some late autumn and winter production. Lucerne cultivars vary in their response to climatic conditions and cultural practices. Thus while cv 'Saranac' used by Fraser (1982) and cv. WL320 used in this trial were both classified as semi-dormant (Challenge Seeds, 1989), their winter productions were different. Fraser (1982) recorded no winter yields from Saranac but WL320 produced very high winter yields in this trial especially in the warm winter of 1989 (Table 3.9 and 4.3). Water stress in summer may have increased the cold tolerance as reported by Levitt (1972) as well as increased the root carbohydrate concentrations of lucerne (Sheafer and Barnes, 1982), resulting in the high winter yields in 1989. However, Lucas (1984) found that Saranac gave 710 and 2850 kg $DMha^{-1}$ in July and September 1983 respectively, demonstrating its potential to produce in winter.

Both WL320 and Saranac are also classified as moderately resistant to pea-aphid (*Acyrthosiphon pisum Harris*). No incidence was recorded on WL320 during the duration of the present study. Thus the specifications available from seed companies or breeders are not always precise. The environmental and cultivar interaction needs further study preferably using three contrasting cultivars: winter-active, semi-dormant and dormant in order to assess their suitability for use in mixed cultures with grasses.

WL320 proved to be very resistant to severe drought as well as severe grazing. Even in the shallow soils, it maintained good stand population after the extremely dry summer of 1988/89. Its ability to recover after very close grazing shows that WL320 is not sensitive to overgrazing. In mixtures with prairie grass and phalaris, WL320 produced well under both short and long grazing durations. These qualities and its resistance to several important

lucerne pests and diseases suggest that WL320 is potentially a very useful lucerne cultivar warranting further research on its attributes as an associate legume for grasses. Perhaps used in conjunction with shorter spelling periods, its compatibility with phalaris can be improved, and may provide the desired lucerne/grass mixture.

CHAPTER 6

RECOMMENDATIONS AND SUGGESTIONS FOR FUTURE WORK

The overall objective of this research project was to improve the current knowledge on lucerne and grass mixtures. The results from the grazing duration study (Chapter 3) should provide some practical guidelines on the management of lucerne/grass pastures to maximise their production and persistence. Similarly the results from the study on the effects of soil depth (Chapter 4) should provide guidelines in the choice of pasture type (pure lucerne or lucerne/grass mixtures) and in the choice of companion grass species for lucerne under different conditions of soil depth and moisture.

Based on the results of the present research and inferences drawn from previous studies, the following recommendations of practical importance in dryland farming can be made:

(1) In shallow soils with low rainfall, lucerne should normally be sown only in pure stands, but phalaris may be sown with lucerne where weed control is desired. Phalaris is unlikely to make a major contribution to pasture production in the first few years, but it may occupy potentially bare space as the lucerne stand thins out.

(2) Lucerne/phalaris grazing should be based on the stage of maturity of lucerne at grazing to manipulate the proportion of lucerne and grass in the mixture. Grazing after flowering would favour lucerne, and at vegetative stage would create a longer lag phase in lucerne regrowth and favour phalaris.

(3) In deeper soils, prairie grass should be sown with lucerne to maintain weed control and to provide winter grazing.

(4) Lucerne/prairie grass balance can be maintained by long grazing durations and/or long spells to favour lucerne and short durations and/or short spells to favour grass.

Further work is necessary on lucerne/prairie grass and lucerne/phalaris mixtures to harness their potential use as an alternative pasture for the dryland areas of New Zealand. Research needs to be carried out in the following areas:

(1) The seasonal interactions between grazing duration and regrowth periods/rotation lengths on the productivity and composition of lucerne/grass mixtures.

(2) The use of N, P, and K applications as an alternative method to grazing management for manipulating the pasture composition of lucerne/grass mixtures.

(3) The animal production potential (including toxic effects if any) of lucerne/prairie grass and lucerne/phalaris mixtures in comparison to conventional white clover/ryegrass and pure lucerne pastures.

(4) The amount of nitrogen fixation and transfer from lucerne to associating grasses under dryland conditions and the effect of grass species on nodulation rate of lucerne.

(5) The relationship between water extraction and rooting patterns of lucerne and grasses in pure and mixed stands.

(6) The long-term stability and persistence of lucerne/prairie grass and lucerne/phalaris mixtures under various management regimes.

(7) The establishment methods of lucerne/grass mixtures (e.g. sowing grass at the same time as lucerne; over-drilling grass into older stands of lucerne which are declining in productivity) using different seeding rates and sowing times.

(8) The effects of grazing and spelling durations on soluble carbohydrate root reserves of the lucerne and grass components in mixtures.

(9) The suitability of different lucerne cultivars with varying degrees of winter activity for their sociability with grasses.

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APPENDIX 1

Layout of the grazing trial of lucerne/grass mixtures

1 LS	5 LBL	3 LPS	6 LPL	4 LL	8 L	2 LBS	7 S	Rep. I
b				a				
6 LPL	4 LL	2 LBS	1 LS	8 L	5 LBL	7 S	3 LPS	Rep. II
c				b				
5 LBL	3 LPS	1 LS	7 S	2 LBS	8 L	6 LPL	4 LL	Rep. III
a				c				
8 L	6 LPL	2 LBS	3 LPS	7 S	4 LL	5 LBL	1 LS	Rep. IV
a				a				

Treatments

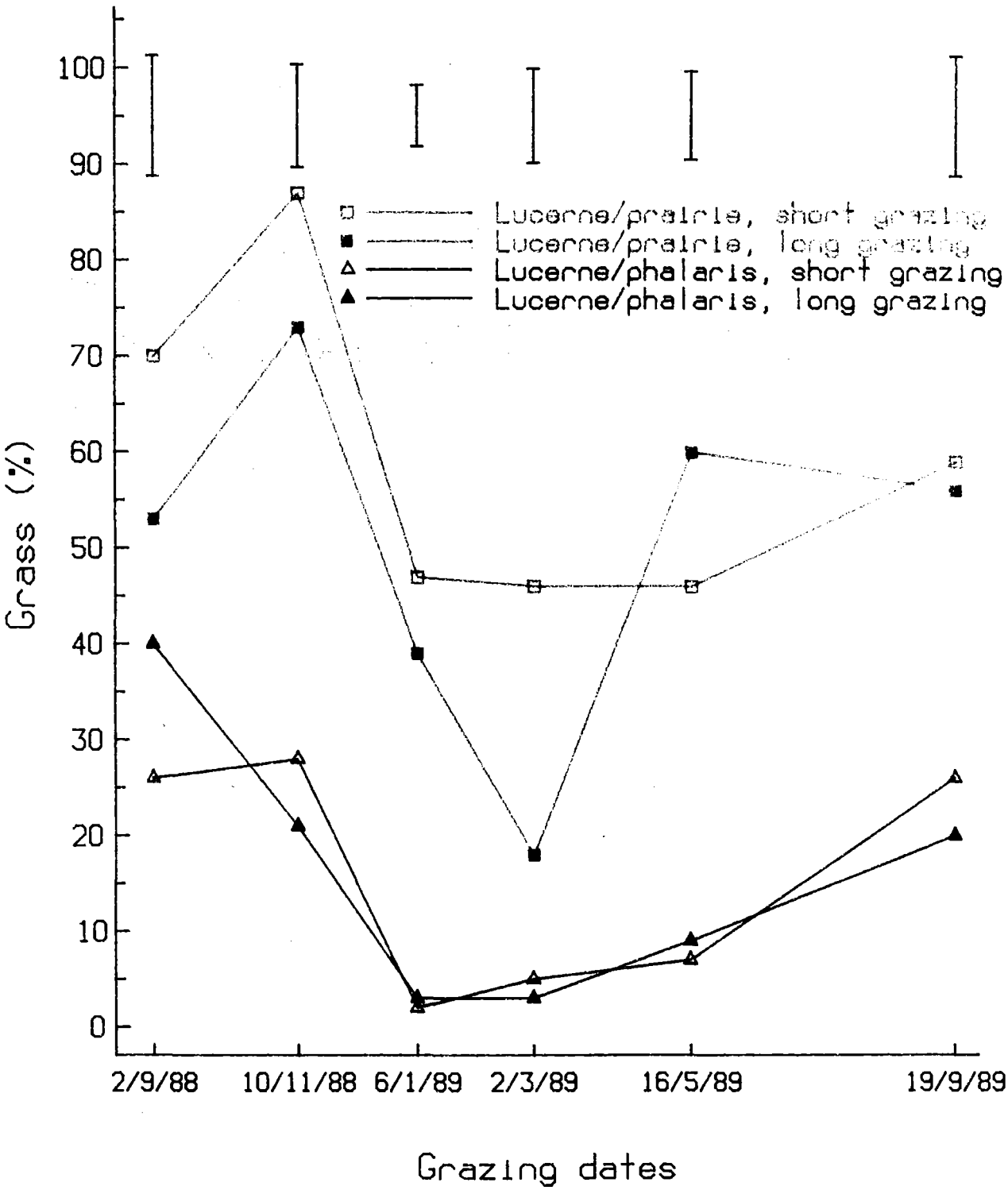
1 LS Lucerne (short grazing duration)
2 LBS Lucerne/prairie grass (short grazing duration)
3 LPS Lucerne/phalaris (short grazing duration)
4 LL Lucerne (long grazing duration)
5 LBL Lucerne/prairie grass (long grazing duration)
6 LPL Lucerne/phalaris (long grazing duration)
7 S Lucerne spare plots (short grazing duration)
8 L Lucerne spare plots (long grazing duration)

Access races

a. Nui ryegrass/Huia white clover
b. Matua prairie grass/Huia white clover
c. Maru phalaris/Huia white clover

APPENDIX 2

The effect of grazing duration on the proportion of grass (% of total yield) in lucerne/prairie grass and lucerne/phalaris mixtures at different grazing dates (Bars = S.E.M.)



APPENDIX 3

```
C
C     Main program for neutron probe analysis package
C     ==== ======= === ======= ===== ======== =======
C
C     Creation date                    2/11/81
C     Date of last update   17/11/81
C     Programmer                       Bruce Gear
C     Filename              'NEUTRON.FOR'
C
C     Subroutines for this package are INDATA (INDATA.FOR),
C                SORT (SORT.FOR)
C
C     SITE      L*1      81        String containing a description of the
C                                  experiment.
C     OBS       L*1      41        String containing the observers name.
C     GROUND    L*1      16        Ground conditions
C     PROBE     L*1      7         Probe type SCALAR or METER
C     DAT       L*1      21        Date of observation
C     TIM       L*1      11        Time of observation
C     DTAFLG    L*1                Flag specifying which input is
C                                  required from the subroutine INDATA.
C     BYTORG    L*1      20        String to hold the character
C                                  representation of the origin of the
C                                  output graph.
C     FILE      L*1      40        String to hold the name of the input
C                                  and output filenames when opening
C                                  these files.
C
C     PLOTNO    I*4                Number of the plot for the current
C                                  data set.
C     TUBENO    I*4                Number of the tube for the current
C                                  data set
C     L         I*4                Contains the length of the filename
C                                  entered from the terminal
C     CTWATR    I*4                SCALAR probe Count time for water
C     CWATER    I*4                  "     "  Counts for water
C     CTSOIL    I*4                  "     "  Count time for soil and shield
C     SHIELD    I*4                  "     "  Shield count
C     HEIGHT    I*4                Tube height above ground
C     NODPTH    I*4                Number of depths
C     NOREAD    I*4                Number of readings at each depth
C     DPGRAV    I*4                Depth of gravimetric reading
C     DEPTH     I*4      100       Array to hold the depth in centimetres of
C                                  each level
C     READNG    I*4      100,10    The readings at the corresponding depths
C     GRAPH     I*4                Variable to hold the number of spaces
C                                  required in front of the * in the graph
C     OLDSHD    I*4                Depending on probe type this contains SHIELD
C                                  or CRINSD from the last data set
C     CRFWTR    I*4                METER probe Count rate for water
C     CRINSD    I*4                  "     "  Count rate in shield
C
C     INT       R*8                Calibration constants Intercept
C     SLOPE     R*8                     "        "    Slope
C     GRAV      R*8                Gravimetric reading
C     THETA     R*8      100,10    Theta for each reading 1-9. 10 contains
C                                  the mean of these.
C     CONLAY    R*8      100       Volumetric water content in layer
C     CONPRO    R*8      100       Volumetric water content in profile
C     GCNLAY    R*8                Gravimetric content in layer
C     GCNPRO    R*8                Gravimetric content in profile
C     MINTHE    R*8                Minimum value of theta for current data set
C     MAXTHE    R*8                Maximum value of theta for current data set
C     STDDEV    R*8      100       Standard deviations
C     ORIGIN    R*8                Origin of graph
C
      BYTE SITE(81),OBS(41),GROUND(16),PROBE(7),DAT(21),TIM(11),
     1  DTAFLG,BYTORG(20),FILE(40)
      INTEGER PLOTNO,TUBENO,L,CTWATR,CWATER,CTSOIL,SHIELD,HEIGHT,
     1  NODPTH,NOREAD,DPGRAV,DEPTH(100),READNG(100,10),
     2  GRAPH,OLDSHD,CRFWTR,CRINSD
      REAL*8 INT,SLOPE,THETA(100,10),CONLAY(100),CONPRO(100),
     1  GTHETA,GCNLAY,GCNPRO,MINTHE,MAXTHE,STDDEV(100),ORIGIN,
     2  GRAV
```

```
C
C Write program heading to terminal
C
      WRITE(5,1000)
C
C Get output filename from the terminal
C
      WRITE(5,1140)
      READ(5,3010,END=99) L,FILE
C
C If <CR> enter on it's own then the default filename in OUTPUT.DAT
C
      IF( L.EQ.0 ) GO TO 180
      FILE(L+1)=0
      OPEN (UNIT=1,NAME=FILE,TYPE='NEW')
      GO TO 190
180   OPEN (UNIT=1,NAME='OUTPUT.DAT',TYPE='NEW')
C
C Get input filename from terminal
C
190   WRITE(5,1150)
      READ(5,3010,END=99) L,FILE
      IF( L.EQ.0 ) THEN
        LUN=5
      ELSE
        LUN=2
        FILE(L+1)=0
        OPEN(UNIT=2,NAME=FILE,TYPE='OLD',ERR=210)
      END IF
      GO TO 220
210   WRITE(5,5020) 7
      GO TO 190
C
C Initialize data set count and input flag
C
220   DTASET=1
      DTAFLG=1
C
C Get current set of input from the terminal
C
10    CALL INDATA(LUN,DTAFLG,SITE,OBS,GROUND,PROBE,DAT,TIM,PLOTNO,
      1  TUBENO,CTWATR,CWATER,CTSOIL,SHIELD,INT,SLOPE,HEIGHT,
      2  NODPTH,NOREAD,GRAV,DPGRAV,DEPTH,READNG,CRFWTR,CRINSD)
C
C Sort the depths and readings into depth order
C
      CALL SORT(DEPTH,READNG,NODPTH)
C
C Output a top of page to the output file
C
      WRITE(1,1110)
C
C Output the page heading for the SCALAR type probe
C
      IF( PROBE(1).EQ.'S' ) WRITE(1,1010)
      1  (SITE(I),I=1,80),(OBS(I),I=1,40),(GROUND(I),I=1,15),
      2  (PROBE(I),I=1,6),(DAT(I),I=1,20),(TIM(I),I=1,10),PLOTNO,
      3  TUBENO,CTWATR,CWATER,CTSOIL,SHIELD,HEIGHT
C
C Output the page heading for the METER type probe
C
      IF( PROBE(1).EQ.'M' ) WRITE(1,1015)
      1  (SITE(I),I=1,80),(OBS(I),I=1,40),(GROUND(I),I=1,15),
      2  (PROBE(I),I=1,6),(DAT(I),I=1,20),(TIM(I),I=1,10),PLOTNO,
      3  TUBENO,CRFWTR,CRINSD,HEIGHT
C
C If this is not the first set of data and the value of SHIELD has varied by
C more than 5% for the SCALAR probe input then print a warning to the output
C file.
C
      IF( DTASET.NE.1 .AND. PROBE(1).EQ.'S' .AND. ABS(SHIELD-OLDSHD).GT.
      1  0.05*OLDSHD ) WRITE(1,1020)
C
C If this is not the first set of data and the value of CRSIND has varied by
C more than 5% for the METER probe input then print a warning to the output
C file.
```

```
C
      IF( DTASET.NE.1 .AND. PROBE(1).EQ.'M' .AND. ABS(CRINSD-OLDSHD).GT.
     1  0.05*OLDSHD ) WRITE(1,1025)
C
C Change data flag so as to skip the initial input (i.e. SITE, OBSERVER,
C ETC) the next time we call INDATA
C
      DTAFLG=2
C
C Increment the data set count
C
      DTASET=DTASET+1
C
C Save the current value of SHIELD (SCALAR probe) for testing the
C next data set
C
      IF( PROBE(1).EQ.'S' ) OLDSHD=SHIELD
C
C Save the current value of CRSIND (METER probe) for testing the
C next data set
C
      IF( PROBE(1).EQ.'M' ) OLDSHD=CRINSD
C
C Initialize the variables to hold the maximum and minimum values of THETA.
C
      MAXTHE=0.0
      MINTHE=99999.0
C
C Calculate the average count and standard deviation for each level
C
      DO 140 INDP=1,NODPTH
      READNG(INDP,10)=0
C
C Sum the readings for this level
C
      DO 150 INRD=1,NOREAD
      READNG(INDP,10)=READNG(INDP,10)+READNG(INDP,INRD)
150   CONTINUE
C
C Divide by the number of readings to obtain the average
C
      READNG(INDP,10)=READNG(INDP,10)/NOREAD
C
C Now calculate the standard deviation
C
      STDDEV(INDP)=0
      DO 160 INRD=1,NOREAD
      STDDEV(INDP)=STDDEV(INDP)+(READNG(INDP,INRD)
     1  -READNG(INDP,10))**2
160   CONTINUE
      STDDEV(INDP)=SQRT(STDDEV(INDP)/NOREAD)
140   CONTINUE
C
C Calculate theta for each level
C
      DO 20 INDP=1,NODPTH
C
C Is the depth of the current level deeper than the gravimetric depth
C
      IF( DPGRAV.NE.0 .AND. DEPTH(INDP).LT.DPGRAV ) GO TO 20
C
C Calculate THETA for this reading level (probe type SCALAR).
C
      IF( PROBE(1).EQ.'S' ) THETA(INDP,10)=INT+
     1  (READNG(INDP,10)*CTWATR)*SLOPE/(CWATER*CTSOIL)
C
C Calculate THETA for this reading level (probe type METER).
C
      IF( PROBE(1).EQ.'M' ) THETA(INDP,10)=INT+SLOPE*
     1  READNG(INDP,10)/CRFWTR
C
C Test whether this value for theta is the new maximum or new minimum
C value of THETA.
C
      IF( THETA(INDP,10).LT.MINTHE ) MINTHE=THETA(INDP,10)
      IF( THETA(INDP,10).GT.MAXTHE ) MAXTHE=THETA(INDP,10)
```

```
 20      CONTINUE
C
C Calculate the water content for the gravimetric layer
C
        IF( DPGRAV.EQ.0 ) GRAV=0.0
        IF( DPGRAV.NE.0 .AND. GRAV.LT.MINTHE ) MINTHE=GRAV
        IF( DPGRAV.NE.0 .AND. GRAV.GT.MAXTHE ) MAXTHE=GRAV
        GCNLAY=GRAV*DPGRAV*10
C
C Calculate the water content for the profile down to the gravimetric layer
C
        GCNPRO=GCNLAY
C
C Find the first set of readings deeper than the gravimetric layer
C
        DO 40 FSTDPT=1,NODPTH
        IF( DEPTH(FSTDPT).GE.DPGRAV ) GO TO 50
 40     CONTINUE
C
C If there is no gravimetric reading then we start with the first set
C of readings
C
 50     IF( DPGRAV.EQ.0 ) FSTDPT=1
C
C Calculate the water content for each layer
C
        IF( DPGRAV.EQ.0 ) THEN
          CONLAY(FSTDPT)=10*THETA(FSTDPT,10)*DEPTH(FSTDPT)
        ELSE IF( DEPTH(FSTDPT).EQ.20 ) THEN
            CONLAY(FSTDPT)=GCNLAY
          ELSE
            CONLAY(FSTDPT)=10*((THETA(FSTDPT,10)+GRAV)/2)
        1     *(DEPTH(FSTDPT)-DPGRAV)
        END IF
        DO 200 INDP=FSTDPT+1,NODPTH
        CONLAY(INDP)=10*((THETA(INDP,10)+THETA(INDP-1,10))/2)
        1  *(DEPTH(INDP)-DEPTH(INDP-1))
 200    CONTINUE
C
C The water content of the profile at the first set of reading is the
C water content at this layer plus the water content of the profile to
C the gravimetric layer
C
        CONPRO(FSTDPT)=GCNPRO+CONLAY(FSTDPT)
        IF( DEPTH(FSTDPT).EQ.20 ) CONPRO(FSTDPT)=GCNPRO
C
C For the remaining readings the water content of the profile is the
C sum of the water content at the current level and the water content of
C the profile at the previous level
C
        DO 60 INDP=FSTDPT+1,NODPTH
        CONPRO(INDP)=CONLAY(INDP)+CONPRO(INDP-1)
 60     CONTINUE
C
C Find out the origin for the graph. (i.e. origin is 0 or MINTHE )
C
        IF( MINTHE.EQ.MAXTHE .AND. MAXTHE.NE.0.0 ) MINTHE=MAXTHE-1
C
C Output message
C
        WRITE(5,1080) MINTHE,MAXTHE
 110    WRITE(5,1090) MINTHE
C
C Read value of origin from terminal
C
        READ(5,*,END=99,ERR=90) ORIGIN
C
C Check if ORIGIN is in the correct range
C
        IF( ORIGIN.LE.MINTHE ) GO TO 170
C
C In the wrong range so output error message and branch back to ask
C user to try again
C
        WRITE(5,5010) 7
        GO TO 110
```

```
C
C Error during the read assume user didn't enter a number so output
C an error message and branch back for the user to try again
C
 90     WRITE(5,5000) 7
        GO TO 110
 170    MINTHE=ORIGIN
C
C Convert MINTHE (i.e. the value for the origin into characters to enable a
C nice output)
C
        ENCODE(10,7000,BYTORG) MINTHE
C
C Find first non-blank character so that we can left justify
C
        DO 120 INDORG=1,10
        IF( BYTORG(INDORG).NE.' ' ) GO TO 130
        BYTORG(INDORG+10)=' '
 120    CONTINUE
C
C Write out table heading
C
 130    WRITE(1,1030) (BYTORG(I),I=INDORG,INDORG+9),MAXTHE
C
C If there is no gravimetric reading then we can't write it out
C
        IF( DPGRAV.EQ.0 ) GO TO 80
C
C Calculate the number of spaces for the graph
C
        GRAPH=30
        IF( MINTHE.NE.MAXTHE ) GRAPH=(GRAV-MINTHE)/(MAXTHE-MINTHE)*29
C
C Write the value for the gravimetric layer
C
        IF( GRAPH.NE.0 ) WRITE(1,1040)GRAV,GCNLAY,GCNPRO
        IF( GRAPH.EQ.0 ) WRITE(1,1050)GRAV,GCNLAY,GCNPRO
C
C Write the values for the layers deeper than the gravimetric layer
C
 80     DO 70 INDP=FSTDPT,NODPTH
        GRAPH=30
C
C Calculate the number of spaces for the graph
C
        IF( MINTHE.NE.MAXTHE ) GRAPH=( THETA(INDP,10)-MINTHE )/
        1  ( MAXTHE-MINTHE )*29
C
C 4 combinations of writes are required depending on whether there
C is 1 depth or more (i.e. is there a std dev.) and whether the value
C to be graphed is equal to the origin
C
        IF( GRAPH.NE.0 .AND. NOREAD.NE.1 ) WRITE(1,1060) DEPTH(INDP),
        1  READNG(INDP,10),STDDEV(INDP),THETA(INDP,10),CONLAY(INDP),
        2  CONPRO(INDP)
        IF( GRAPH.NE.0 .AND. NOREAD.EQ.1 ) WRITE(1,1065) DEPTH(INDP),
        1  READNG(INDP,10),THETA(INDP,10),CONLAY(INDP),CONPRO(INDP)
        IF( GRAPH.EQ.0 .AND. NOREAD.NE.1 ) WRITE(1,1070) DEPTH(INDP),
        1  READNG(INDP,10),STDDEV(INDP),THETA(INDP,10),CONLAY(INDP),
        2  CONPRO(INDP)
        IF( GRAPH.EQ.0 .AND. NOREAD.EQ.1 ) WRITE(1,1075) DEPTH(INDP),
        1  READNG(INDP,10),THETA(INDP,10),CONLAY(INDP),CONPRO(INDP)
 70     CONTINUE
C
C If there were readings given above the gravimetric depth print a warning
C
        IF( FSTDPT.NE.1 ) WRITE(1,1120)
C
C Write out comment about gravimetric readings
C
        WRITE(1,1130)
C
C Prompt for next data set
C
        IF( LUN.EQ.5 ) WRITE(5,1100)
        GO TO 10
```

```
C
C Execution aborted via <CTRL> Z
C
 99      STOP
C
C Prompt and output formats
C
 1000    FORMAT(//'0',10X,'Neutron Probe Analysis Program'/
         1  11X,7('*'),1X,5('*'),1X,8('*'),1X,7('*')//)
 1010    FORMAT(///' ',20X,5('*'),'NEUTRON MOISTURE METER ANALYSIS',5('*')/
         1  ' ',25X,7('_'),1X,8('_'),1X,5('_'),1X,8('_')///'0Site: ',80A1/
         2  '0Observer: ',40A1,5X,' Ground conditions: ',15A1/
         3  '0Probe type: ',6A1,5X,'Date: ',20A1,5X,' Time: ',10A1,5X,
         4  ' Plot number: ',I3,5X,'Tube number: ',I3/
         5  '0Count time for water: ',I4,2X,' Counts for water: ',I5,2X,
         6  ' Count time for soil and shield: ',I4,5X,' Shield count: ',
         7  I5/'0Tube height above ground: ',I3///)
 1015    FORMAT(///' ',20X,'Neutron Probe Analysis'/' ',20X,7('_'),
         1  1X,5('_'),1X,8('_')/'0Site: ',80A1/
         2  '0Observer: ',40A1,' Ground conditions: ',15A1/
         3  '0Probe type: ',6A1,' Date: ',20A1,' Time: ',10A1,
         4  ' Plot number: ',I3,' Tube number: ',I3/
         5  '0Count rate for water: ',I4,' Count rate in shield: ',
         6  I4/'0Tube height above ground:',I3///)
 1020    FORMAT(' ****** WARNING: Shield count varies by more than 5% from',
         1  ' previous reading'//)
 1025    FORMAT(' ****** WARNING: Count rate in shield varies by more than',
         1  ' 5% from previous reading'//)
 1030    FORMAT(17X,'Average counts',4X,'Volumetric soil',2(4X,'Water co',
         1  'ntent'),6X,'Depth vs Volumetric Water content'/8X,'Depth',
         2  4X,' +/- Std. dev.',5X,'Water content',7X,'Per layer',7X,
         3  'In profile'/8X,'(cm)',25X,'(cu.m/cu.m)',11X,'(mm)',14X,
         4  '(mm)',9X,10A1,11X,F10.3,/8X,5('-'),4X,14('-'),4X,15('-'),
         5  4X,13('-'),4X,13('-'),6X,'+',29('-'),'+'/90X,'!')
 1040    FORMAT(2X,'*',5X,'0-20',25X,F10.3,8X,F10.1,8X,F10.1,7X,'!',
         1  <GRAPH>X,'*'/90X,'!')
 1050    FORMAT(2X,'*',5X,'0-20',25X,F10.3,8X,F10.1,8X,F10.1,7X,'*'/
         1  90X,'!')
 1060    FORMAT(8X,I3,6X,I5,2X,F7.3,6X,F10.3,8X,F10.1,8X,F10.1,7X,'!',
         1  <GRAPH>X,'*'/90X,'!')
 1065    FORMAT(8X,I3,6X,I5,15X,F10.3,8X,F10.1,8X,F10.1,7X,'!',<GRAPH>X,
         1  '*'/90X,'!')
 1070    FORMAT(8X,I3,6X,I5,2X,F7.3,6X,F10.3,8X,F10.1,8X,F10.1,7X,'*'/
         1  90X,'!')
 1075    FORMAT(8X,I3,6X,I5,15X,F10.3,8X,F10.1,8X,F10.1,7X,'*'/90X,'!')
 1080    FORMAT('0A graph of depth vs volumetric soil water content will',
         1  ' be produced. The range'/' of values for the volumetric soil',
         2  ' water content is',F10.3,' to',F10.3,'.')
 1090    FORMAT('$Specify the origin for the volumetric axis (less',
         1  ' than',F10.3,') :')
 1100    FORMAT('0Next data set'/1X,4('='),1X,4('='),1X,'==='/
         1  ' Enter <CTRL>Z to exit from the program'/)
 1110    FORMAT('1')
 1120    FORMAT('0****** WARNING: Readings of depths at or above the',
         1  ' gravimetric depth have been ignored')
 1130    FORMAT('0* Gravimetric reading')
 1140    FORMAT('$Enter output filename :')
 1150    FORMAT('$Enter input filename (<CR> for input from terminal) :')
C
C Input format statements
C
 3000    FORMAT(I1)
 3010    FORMAT(Q,40A1)
C
C Error format statements
C
 5000    FORMAT(' ***** ERROR: Numerical input required',A1)
 5010    FORMAT(' ***** ERROR: Number out of range',A1)
 5020    FORMAT(' ***** ERROR: Input file was not found. Please try',
         1  ' again',A1)
C
C Encode format statement
C
 7000    FORMAT(F10.3)
         END
```

APPENDIX 4

Sample Output of general linear models procedure used in analysing data from the soil depth experiment.

Dependent Variable: Total Yield

Source	DF	Sum of Squares	Mean Square	F Value
Model	5	7642973.90	1528594.78	6.27
Error	34	8289552.87	243810.37	PR > F
Corrected Total	39	15932526.77		0.0003

R-Square	C.V.	Root MSE	TOT Mean
0.479	24.02	493.77	2054.92

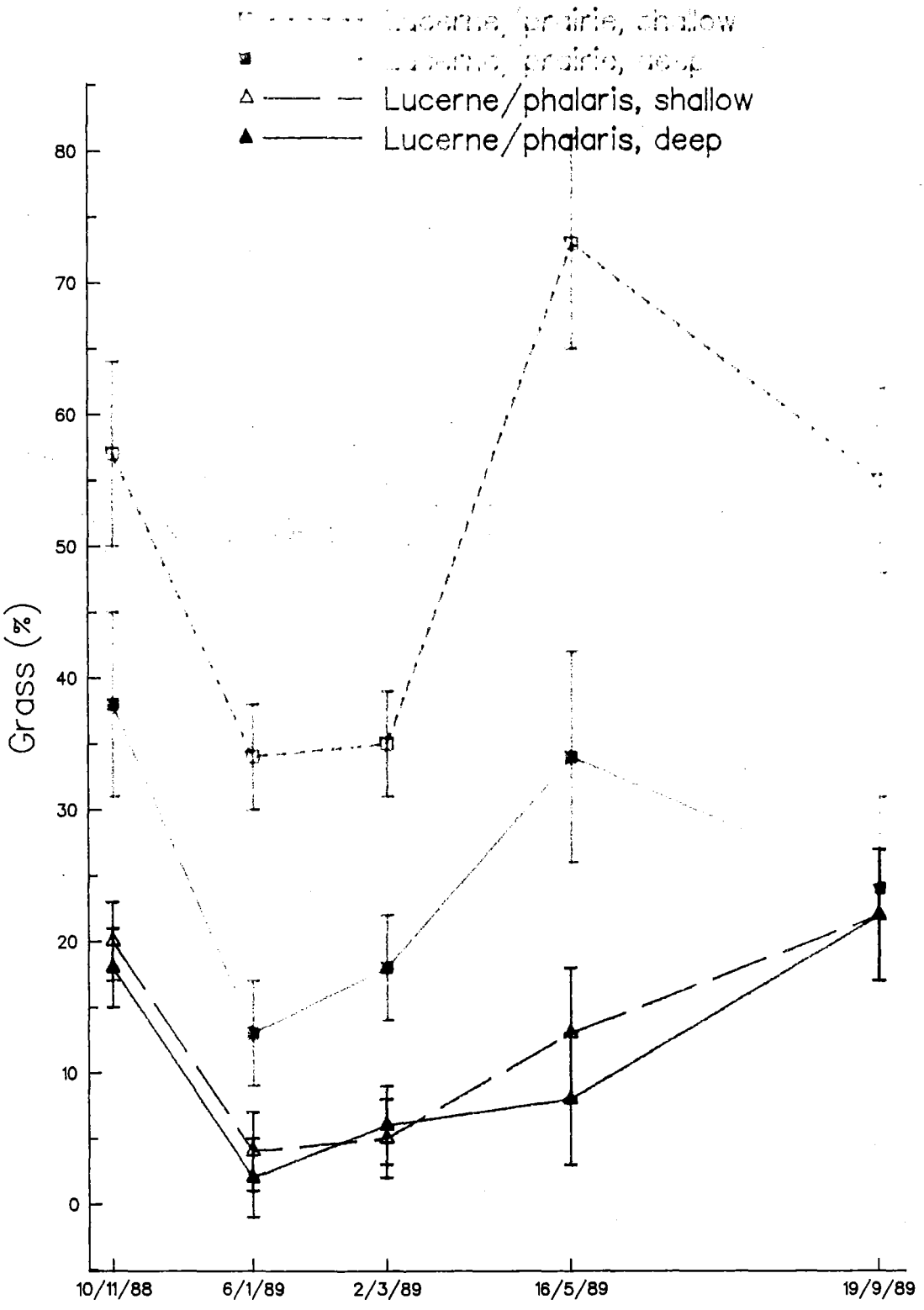
Source	DF	Type I SS	F Value	PR > F
Past	2	3534845.58	7.25	0.0024
Depth	1	3486312.02	14.30	0.0006
Past*Depth	2	621816.28	1.28	0.2924

Source	DF	Type III SS	F Value	PR > F
Past	2	3534845.58	7.25	0.0024
Depth	1	3723452.64	15.27	0.0004
Past*Depth	2	621816.28	1.28	0.2924

Pasture by depth trial second cut

APPENDIX

Grass dry matter yield as a percentage of total dry matter yields of lucerne/grass mixtures in shallow and deep soils at different grazing dates (Bars=S.E.M.).



APPENDIX 6

Effects of pasture type and soil profile depth on weed yields in September 1989 (kg $DMha^{-1}$).

PASTURE TYPE	SOIL DEPTH	
	shallow	deep
Lucerne	280	500
Lucerne/prairie grass	0	20
Lucerne/phalaris	60	90
LSD (P<0.05)		
1-2; 2-3	210	
1-3	150	
Interaction (P)	0.12	

APPENDIX 7

Root yields (kg DMm^{-3}) of pure pastures of legumes and grasses at different soil depths (Figure 4.12)

Soil Depth (cm)	a) Lucerne	b) Prairie grass	c) Phalaris	d) Perennial ryegrass
0-20	11.87	6.31	4.42	3.26
20-30	2.69	0.55	1.19	0.13
30-40	0.71	0.19	0.91	0.09
40-50	0.65	0.23	0.33	0
50-60	0.31	0.19	0.25	0
60-70	0.17	0.08	0.25	0
70-80	0	0	0	0

APPENDIX 8

Root yields (kg DMm^{-3}) of mixed pastures of legumes and grasses at different soil depths (Figure 4.12).

Soil Depth (cm)	a) Lucerne/prairie mixture		b) Lucerne/phalaris mixture		c) Lucerne/ryegrass mixture	
	Lucerne	Prairie	Lucerne	Phalaris	Lucerne	Ryegrass
0-20	3.73	2.49	8.66	1.20	9.22	2.06
20-30	1.27	0.36	2.56	0.81	1.61	0.06
30-40	0.33	0.18	1.37	0.25	2.78	0
40-50	0.22	0.10	1.19	0.31	2.09	0
50-60	0.09	0	0.46	0.25	0.41	0
60-70	0.10	0	0.51	0.28	0.40	0
70-80	0	0	0.30	0.07	0	0